NASA/TM-2004-213017

Suggested Procedures for Installing Strain Gauges on Langley Research Center Wind Tunnel Balances, Custom Force Measuring Transducers, Metallic and Composite Structural Test Articles

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May 2004

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ABSTRACT:
The character of force and strain measurement testing at LaRC is such that the types of strain gauge installations, the materials upon which the strain gauges are applied, and the test environments encountered, require many varied approaches. These strain gauge installations must be accomplished in the most technically discerning and appropriate manner. In 1997, a NASA Technical Memorandum (NASA TM 110327) was generated to provide the strain gauge application specialist with a listing of `recommended procedures` for strain gauging various transducers and test articles at LaRC. The technical memorandum offered here is an effort to keep the strain gauge user informed of new technological enhancements in strain-gauging methodology while preserving the strain-gauging guidelines set forth in the 1997 TM. Basically, this document is written to help the strain gauge application specialist and the strain gauge user in determining the appropriate approach for a given strain gauge application requirement and to offer materials and step-by-step direction for certain strain gauging tasks. Additionally, this document provides details for installing Bragg-Grating type fiber-optic strain sensors for non-typical test scenarios. Specifically, this document offers detailed recommendations for strain gauging the following: **LaRC-designed balances, LaRC custom transducers, certain composite materials and metallic alloys, cryogenic and high-temperature test articles, selected non-typical or unique materials or test conditions, and installation procedures for applying certain fiber-optic strain sensors.**

INTRODUCTION:
Ever changing and often challenging demands in the area of strain measurements dictate that strain-gauging materials (including fiber-optic strain sensors) and application procedures be periodically updated. More demanding test environments on more complex test articles have brought about the development and incorporation of new types of strain-gauging materials and strain sensors for today's testing endeavors. A portion of this technical memorandum will revisit and update the information furnished in the NASA TM 110327. It should be noted that this document, unlike the NASA TM 110327, does not offer gauging procedures for testing above 700°F. The recommendations contained in that document for strain gauging test articles above 700°F are still applicable. The remainder of this TM will address recently developed application procedures for installing Bragg-Grating type fiber-optic (F-O) strain sensors. The other widely used type of fiber-optic strain sensor is the EFPI fiber-optic strain sensor. It has been available commercially for some time now and since application procedures for that type of sensor are straightforward and routinely furnished with the sensor, it was decided to forgo any inclusion of application procedures in this text. This document is offered to provide proven approaches and materials used for many of the testing programs at NASA Langley that require strain measurements. Of course, there are a multitude of strain-gauging activities that will require far different methods and materials from those offered here. There is no intent to imply that the methods and materials offered in this document are the best possible for any given strain gauge endeavor.

EXPLANATION NOTES FOR CERTAIN TERMINOLOGY USED IN TEXT:
1. For this TM, the suggested procedures for installing strain gauges and fiber-optic strain sensors are listed and described by **"APPLICATION CLASS"** with **"INSTALLATION TYPE"** within each designated class. There are five (V) distinct classes of strain gauge, or strain sensor, application. Within each "application" class there are several "installation" types. As appropriate, strain-gauging materials

(including strain gauge type), surface preparation, installation techniques, wiring considerations, protective coatings, and technical notations are presented.

2. The materials listed for surface preparation for strain gauge installations are recommendations only, and are continually being updated. Therefore, the materials listed for "Surface Preparation for Gauging" are those that are currently recommended and are considered to be somewhat arbitrary.

3. When "room temperature" is stated with respect to gauge installation procedures it is understood that the actual temperature of the article being strain-gauged and the surrounding air temperature is at least 72°F and not more than 80°F. It is also understood that the relatively humidity is never more than 40% in the work environment.

SUGGESTED STRAIN GAUGE APPLICATION PROCEDURES

ADDENDUM SUMMARY:

<u>APPLICATION CLASS I</u> – STRAIN GAUGE INSTALLATION PROCEDURES FOR ALL LANGLEY WIND TUNNEL BALANCES

INSTALLATION TYPE 1 – Standard Langley 6-Component Balances Operating in 0°F to 200°F Range

NOTES: The following materials and procedures are applicable for Langley balances operating at temperatures between 0°F and 200°F. Apparent strain corrections are made for the temperature range of 80°F to 180°F. There are custom Langley balances that are required to operate at temperatures between 200°F and 300°F. For strain-gauging these balances, the application procedure described in **<u>APPLICATION CLASS II</u>, INSTALLATION TYPE 3** was used as a guide.

<u>Gauging Materials (all materials that are an integral part of the balance)</u>

1. Gauge type: to be designated by design engineer, typically type: C-891113-A (Vishay Micro-Measurements)
2. Adhesive type for applying gauges: M-BOND 610 (Vishay Micro-Measurements); adhesive type for PRT's when required: EA-934 (Hysol)
3. Wiring Terminals type: CPF series (Vishay Micro-Measurements); size of balance determines which size(s) to use
4. Insulation Pads for Apparent Strain Correction Wire and Zero Correction Wire when required, type: Kapton, 1-mil, etched
5. Gauge-to-Terminal Jumper Wire: single strand, AWG#40, silver-clad copper
6. Apparent Strain Correction Wire when required, type: Nickel, size and location(s) within the bridge determined by the design of the balance and the amount required for correction
7. Zero Offset Correction Wire when required, type: Manganin (Vishay Micro-Measurements); size determined by amount required for correction
8. Interconnecting wiring between gauges and/or between bridges, Wire: typically, AWG#30(7-38), AWG#32(7-40), or AWG#36(7-44). This wiring consists of 7 strands of silver-clad copper wire with Teflon insulation. Balance size will determine wire size. Some small balances will require single conductor solid copper, AWG#40 or AWG#42.
9. Balance to Tunnel Connector (either integrated into balance sting or at end of exit leadwires): determined by design engineer, user facility dependant
10. Exit Leadwires (when used in lieu of integral connector): size and length determined by design engineer
11. Solder type: 361A (Vishay Micro-Measurements)
12. Thermocouples when required, type: "J", size typically AWG#36, with Teflon insulation
13. Platinum Resistance Thermometers (PRT's) when required, type: EL-700T (Hy-Cal)
14. Protective Coating over exposed solder joints and uninsulated wiring, typically, type: Gagekote #8 (Vishay Micro-Measurements)
15. Protective Sleeving over Exit Leadwires when required, type: nylon or fiberglass, determined by the design engineer

Surface Preparation for Gauging

1. Degrease the entire balance. This is typically accomplished with a vapor degreasing solvent rinse, types: ENSOLV (Envirotech) or Hypersolve (Ecolink).
2. Perform microscopic examination of the balance looking for flaws in surface, cracked beams, sharp edges, etc.
3. Rinse the entire balance with ethyl alcohol 200 proof.
4. Mask appropriate areas of the balance for micro-sandblasting operation.
5. Micro-sandblast areas to be gauged using 50 micron Al_2O_3 abrasive powder.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the solvent degreasing and alcohol rinse operations. Installation of the gauges should begin immediately following this step.

Installation of the Gauges

1. Gauges, pretrimmed wiring terminals, and insulation pads when used, should be cleaned with 200 proof alcohol, dried, and placed on a clean glass plate. They should be inverted with the undersides up and ready for application of the gauging adhesive.
2. Apply a coat of M-610 to the underside of the gauges, terminals, etc., as well as a coat to the appropriate balance surfaces.
3. Allow the coated items to air dry at least ten minutes at room temperature (air temperature and balance temperature to be no less than 72°F and relative humidity to be not more than 40 percent).
4. Place the gauges, terminals, etc., on the balance surfaces at predetermined locations and cover with a thin, pressure-sensitive Teflon tape.
5. Next, place silicone rubber pads over the tape in the areas where the gauges, terminals, etc., are located.
6. Apply a constant and uniform pressure of 60psi to the rubber pads using an appropriate clamping device.
7. Place the balance in a temperature chamber and slowly raise the temperature of the balance to 340°F. The heating rate should be approximately 6°F/minute.
8. Hold the balance at this temperature for one hour, then, cool the balance through simple convection means.
9. Once the balance is cool, remove the clamping device, the rubber pads, and the tape. Microscopically, inspect the gauge installations for accuracy of gauge positioning and alignment, glue-line voids, or foreign matter. The tolerance for location of the gauge on the balance is typically ±0.005" of the stated location as per the balance strain gauge drawing unless otherwise stated.
10. Typically, several cure cycles are required to install all of the gauges on the balance. The gauging areas that will require gauges during the subsequent curing cycles should be micro-sandblasted again, prior to each gauge installation operation, repeating the surface preparation steps previously outlined.
11. To post cure the gauge installations, slowly raise the temperature at the same heating rate used for the gauge installations until a balance temperature of 340°F is reached. Hold the balance at that temperature for two hours. Cool the balance and repeat the microscopic inspection of the gauges.

Wiring the Balance

Note: Because of the considerable variation in balance design and size it is not possible to itemize and detail a standard wiring procedure for all Langley balances in this class. Nonetheless, certain steps can be detailed while others must be generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gauge (to the nearest hundredth of an ohm) at the gauge's solder dots.
2. Using a hard rubber eraser, remove the oxidation from the gauging terminals.
3. Install and solder the gauge jumpers between the gauge dots and the wiring terminals. All soldering for these balances should be performed using the NASA soldering handbook titled, "NHB 5300.4(3A-1)" as a guide.
4. Remove the flux residue from the solder joints and the gauge jumper wires using a degreasing solvent and a soft brush.
5. Record the resistance of each gauge at the wiring terminals. Compare this to the resistances recorded in Step 1. This will confirm the integrity of the jumper wires and the solder joints at the gauge and the terminals.
6. All strain gauge wiring for balances should be subjected to an insulation resistance test by submerging the wire in regular tap water and measuring the leakage to ground resistance. This resistance should be greater than 10 Gig-ohms.
7. All interconnecting wiring (wiring between gauges and between balance components) must be carefully stripped and tinned prior to installing at its respective terminal. Inspect for anomalies in the insulation and nicks in the strands before tinning.
8. When possible, all interconnecting wiring between gauges in a bridge should be of equal resistance and length.
9. All interconnecting wiring for a given bridge should be snug against the balance surfaces along the entire length of the wire. Do not allow any wiring to span open areas within the balance. When wiring a balance designed for light loads, care must be exercised in preventing the wires from carrying any part of the load that's being applied to the measuring beams. Later, when applying the moisture-proofing, do not allow the moisture-proofing to bond the wiring to the load-carrying (measuring) beams.
10. Wire routing should be preplanned with no wiring routed over the strain gauge active grids or the gauge jumpers.
11. When all wiring is completed the balance should be cleaned to remove all soldering residues and other foreign matter.

Initial Electrical Checks

1. Check the balance components to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be greater than 10 Gig-ohms.
2. Record the bridge electrical zeros. Bridge excitation voltage should be the same as that to be used for the balance when in service. For each balance component, check to confirm that the zero is representative of the arbitrary differences in the resistances of the four gauges that comprise the bridge circuit. The zeros should be within ±0.4mV/V of the calculated zero. This agreement

may be harder to achieve on smaller balances where lightly loaded beams and small interconnecting wiring can affect the calculated zero.

3. The tolerance allowable for the recorded electrical zeros for all components is quoted on the balance drawing. The typical allowance is ±0.4mV/V.
4. Mechanically shunt each gauge within a bridge while observing its electrical zero in order to verify the bridge integrity.
5. When possible, hand-load each component to verify expected sensitivity. Also, check for zero shifts as a function of loading and unloading the balance.

Elevated Temperature Soak Cycles

Prior to commencing apparent strain runs the newly wired balance is to be subjected to a series of thermal cycles as follows: With the balance supported as it will be for the apparent strain correction task, record the electrical zero of each component. Next, heat the balance to 250°F (the heat-up rate should not exceed 6°F/minute). Hold the balance at that temperature for 15 minutes, and then return the balance to room temperature. Repeat the thermal cycling to 250°F and back to room temperature two more times (a total of three thermal cycles). Compare the zeros with the zeros recorded prior to the thermal cycling. A large change in zero in a given component (>0.010mV/V) indicates a potential problem and the component should be investigated further to resolve the source of the zero change. Once the thermal cycling is satisfactorily completed, proceed with the apparent strain correction.

Apparent Strain Correction

Note: Apparent strain correction for this class of balances involves adding temperature-sensitive wire(s) to a given component in order to minimize the change in that component's electrical zero during the temperature excursion from room temperature to 180°F. It should be noted that this correction is made based on the component's zero at 180°F compared to its zero at room temperature. The apparent strain correction does not attempt to correct for changes in zero at discreet temperatures during the temperature excursion between room temperature and 180°F.

1. Place the balance in the temperature chamber horizontally, in the –Normal Force up position, supported at the non-metric end only.
2. The balance should be covered with a non-contacting encasement uniformly constructed such that the balance is not directly exposed to any airflow.
3. For monitoring temperature during the run, attach a thermocouple to the top of the balance in the area of the aft shoulder of the aft cage section using a piece of aluminum tape. If the balance has its own thermocouples or PRT's, utilize the aft one.
4. Connect the balance to the data acquisition system including bridge excitation voltage (bridge voltage is to be the same as that which will be used for the complete balance load calibration.)
5. Allow a 30-minute "warm-up" period with the balance connected to the data acquisition system as in Step 4.

6. At the end of the 30-minute warm-up period, start a “time versus output” recording at “room temperature” with the temperature chamber airflow on and the chamber temperature controller set at 80°F.
7. Continue recording the “room temperature” outputs until all component zeros are stable, i.e., not changing more than 0.001mV/5VDC/5 minutes. The temperature of the monitor thermocouple (or PRT) should also be stable, i.e., not changing more than 0.2°F/minute. Record the actual temperature of the monitor thermocouple at this time.
8. Once Step 7 has been achieved, turn the temperature controller setting to 180°F and allow the balance to heat until a stable temperature, within two degrees of the 180°F target temperature, is indicated with the monitoring thermocouple (or PRT) on the balance. The heat-up rate should not exceed 6°F/minute. The temperature of the monitor thermocouple (or PRT) should also be stable, i.e., not changing more than 0.2°F/minute.
9. Allow the balance to soak at the elevated stabilized temperature until the drift rate of the electrical zero for each component does not exceed 0.001mV/5VDC/5 minutes.
10. Once the drift rate requirement at the 180°F target temperature is achieved, cool the balance to room temperature using the temperature chamber controller as necessary to bring the monitoring thermocouple temperature to the same temperature that was recorded in Step 7 within ±1°F. Continue recording the “room temperature” outputs until all component zeros are stable, i.e., not changing more than 0.001mV/5VDC/5 minutes. The temperature of the monitor thermocouple (or PRT) should also be stable, i.e., not changing more than 0.2°F/minute. Record the actual temperature of the monitor thermocouple at this time.
11. On a worksheet, use the recorded apparent strain run to record the output of each component at 180°F with respect to the “return to room temperature” zero.
12. For each component requiring reduction of its apparent strain, add an appropriate amount of nickel wire to the necessary arm(s) of the bridge circuit to nullify the apparent strain of the bridge. When possible, the correction wire should be added in equal amounts in the two appropriate arms of the bridge. The tolerance allowed for apparent strain is ±0.003mV/V/Δ100°F based on the average slope unless otherwise stated on the gauging drawing. Average slope is defined here as the slope generated from the midpoint between the initial zero at room temperature and the final zero at room temperature and the total output at 180°F.
13. Conduct another apparent strain run as per Step 1 through Step 12.
14. After verifying that the apparent strain outputs are within the specifications for all components, apply the moisture-barrier protective coating (procedure reviewed in next section) over gauge solder dots, gauge jumpers, solder joints, and uninsulated wiring as appropriate.
15. Conduct an initial “moisture-proofed” apparent strain run as per Step 1 through Step 11 to verify that all components are still within the specifications for apparent strain correction. If additional corrections are required, perform those corrections using the procedures in Step 11 and Step 12.
16. Conduct another apparent strain run as per Step 1 through Step 12.
17. Conduct another apparent strain run as per Step 1 through Step 12 in order to verify repeatability of apparent strain outputs with moisture-barrier in place on the balance. All components are to be repeatable with respect to the previous run within ±0.002mV/V at any discreet point throughout the temperature excursion, not to exceed a total output of ±0.003mV/V at 180°F.
18. Following verification that the apparent strain outputs are within the specifications as per Step 12

and Step 17, perform a final microscopic examination of the balance and record final electrical zeros and leakage to ground resistances. The balance should now be ready to be forwarded to the loading calibration laboratory.
Note: The above procedure will require modification for water-cooled balances as follows: Water-cooled balances are to have two apparent strain runs following the apparent strain run as in Step 17. These two runs are to be conducted with the water-cooling apparatus operational on the balance. The second of these two runs requires that all components be repeatable with respect to the previous run within ±0.002mV/V at any discreet point throughout the temperature excursion, not to exceed a total output of ±0.003mV/V at 180°F.

Moisture-proofing Procedure

The procedure for moisture-proofing balances will necessarily vary depending on the size, design, and operational environment of the balance. The steps below are provided only as a “good practice” guide. All balances are to be coated in certain areas with a moisture-barrier coating and the coating is to be applied following the apparent strain run in Step 13 of the previous section. The moisture-barrier is to be Gagekote #8. Generally, it is to be applied as follows:

1. Flush the balance with an appropriate degreasing solution. Follow this with a flushing of 200 proof alcohol.
2. The balance is to be at a temperature between 74°F and 80°F during the coating applications.
3. Coat all gauge solder dots, gauge jumpers, solder joints, and all uninsulated wiring with an initial coat of Gagekote #8. The coating thickness should be 0.005” to 0.007”.
4. Allow this coating to air dry for a minimum of 20 minutes at room temperature.
5. Apply a second coating over the first. This coating should overlap all edges of the first coating.
6. Allow this coating to air dry for a minimum of one hour at room temperature.
7. Return to Step 15 in the previous section.
   Notes: On larger balances, additional Gagekote #8 can be used to keep interconnecting wiring in place on the balance surfaces. When practical, no moisture-proofing is to be applied over the active grid areas of the gauges.

INSTALLATION TYPE 2 – Langley “Cryogenic” Wind Tunnel Balances Operating in -275°F to 150°F Range

NOTES: The following materials and procedures are applicable for typical Langley balances operating at temperatures between –275°F and 150°F. Apparent strain corrections are made for that temperature range. There are now “custom-one-of-a-kind” Langley cryogenic balances in service that are gauged using gauging approaches that are applicable only to those particular balances. This document does not offer details for the gauging approaches used on those balances.

Gauging Materials (all materials that are an integral part of the balance)

1. Gauge type: to be designated by design engineer, typically type: C-891113-B (Vishay Micro-Measurements)

2. Adhesive type for applying gauges: M-BOND 610 (Vishay Micro-Measurements); adhesive type for PRT's when required: EA-934 (Hysol)
3. Wiring Terminals type: CPF series (Vishay Micro-Measurements); size of balance determines which size(s) to use
4. Insulation Pads for Apparent Strain Correction Wire and Zero Correction Wire when required, type: Kapton, 1-mil, etched
5. Gauge-to-Terminal Jumper Wire: single strand, AWG#40, silver-clad copper
6. Apparent Strain Correction Wire when required, type: silver-clad copper, size and location(s) within the bridge determined by the design of the balance and the amount required for correction
7. Axial Differential Compensation Sensors (when required) type: nickel (Vishay-Micro-Measurements)
8. Platinum Resistance Thermometers (PRT's) when required, type: EL-700T (Hy-Cal)
9. Interconnecting wiring between gauges and/or between bridges, Wire: typically, AWG#30(7-38), AWG#32(7-40), or AWG#36(7-44). This wiring consists of 7 strands of silver-clad copper wire with "etched" Teflon insulation. Balance size will determine wire size
10. Solder type: 361A (Vishay Micro-Measurements)
11. Protective Coating over exposed solder joints and uninsulated wiring, typically, type: N-1 (Texas Measurements)
12. Balance to Tunnel Connector (integrated into end of balance sting), type determined by design engineer
13. Sealant Between Connector and Sting, type: RTV-3140 (Dow-Corning)
14. Gaseous Nitrogen Balance Sting Purge Fitting type: Stainless Steel with Teflon O-ring
15. Thread Locking Adhesive for Sting Connector Screws and Purge Fitting, type: Loctite 222
16. Convection Shield, type: TFE Teflon; this must be custom sized to fit the balance

Surface Preparation for Gauging

1. Degrease the entire balance. This is typically accomplished with a vapor degreasing solvent rinse, types: ENSOLV (Envirotech) or Hypersolve (Ecolink).
2. Perform microscopic examination of the balance looking for flaws in surface, cracked beams, sharp edges, etc.
3. Rinse the entire balance with ethyl alcohol 200 proof.
4. Mask appropriate areas of the balance for micro-sandblasting operation.
5. Micro-sandblast areas to be gauged using 50 micron Al_2O_3 abrasive powder.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the solvent degreasing and alcohol rinse operations. Installation of the gauges should begin immediately following this step.

Installation of the Gauges

NOTE: Gauges to be installed on cryogenic balances must first be "matched" for apparent strain considerations. A FSIS Memorandum to Technical Files titled, "Matching Cryogenic Strain Gauges," dated April 18, 1994, details the procedure to be utilized for matching strain gauges for cryogenic balances. That particular memorandum is included with this document, at the end of the text, as Addendum #1. All strain gauges to be applied to NASA Langley cryogenic balances must first be "matched" using the above referenced technical memorandum.

1. At this point, the matched gauges have been cleaned, cataloged, and placed in their respective pockets in a custom gauge organizer. Pretrimmed wiring terminals, and insulation pads when used, should be cleaned with 200 proof alcohol, dried, and placed on a clean glass plate along with the appropriate gauges. They should be inverted with the undersides up and ready for application of the gauging adhesive.
2. Apply a coat of M-610 to the underside of the gauges, terminals, etc., as well as a coat to the appropriate balance surfaces.
3. Allow the coated items to air dry at least ten minutes at room temperature (air temperature and balance temperature to be no less than 72°F and relative humidity to be not more than 40 percent).
4. Place the gauges, terminals, etc., on the balance surfaces at predetermined locations and cover with a thin, pressure-sensitive Teflon tape.
5. Next, place silicone rubber pads over the tape in the areas where the gauges, terminals, etc., are located.
6. Apply a constant and uniform pressure of 60psi to the rubber pads using an appropriate clamping device.
7. Place the balance in a temperature chamber and slowly raise the temperature of the balance to 340°F. The heating rate should be approximately 6°F/minute.
8. Hold the balance at this temperature for one hour, then, cool the balance through simple convection means.
9. Once the balance is cool, remove the clamping device, the rubber pads, and the tape. Microscopically, inspect the gauge installations for accuracy of gauge positioning and alignment, glue-line voids, or foreign matter. The tolerance for location of the gauge on the balance is typically ±0.005" of the stated location as per the balance strain gauge drawing unless otherwise stated.
   NOTE: The Kapton backing and wiring terminals for the "axial differential compensation sensors" can be installed during one of the gauge installation cycles using typical balance gauging techniques.
10. Typically, several cure cycles are required to install all of the gauges on the balance. The gauging areas that will require gauges during the subsequent curing cycles should be micro-sandblasted again, prior to each gauge installation operation, repeating the surface preparation steps previously outlined.
11. To post cure the gauge installations, slowly raise the temperature at the same heating rate used for the gauge installations until a balance temperature of 340°F is reached. Hold the balance at that temperature for two hours. Cool the balance and repeat the microscopic inspection of the gauges.

Wiring the Balance

Note: Because of the considerable variation in balance design and size it is not possible to itemize and detail a standard wiring procedure for all Langley balances in this class. Nonetheless, certain Steps can be detailed while others must be generalized. The Steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gauge (to the nearest hundredth of an ohm) at the gauge's solder dots.
2. Using a hard rubber eraser, remove the oxidation from the gauging terminals.
3. Install and solder the gauge jumpers between the gauge dots and the wiring terminals. All soldering for these balances should be performed using the NASA soldering handbook titled, "NHB 5300.4(3A-1)" as a guide.
4. Remove the flux residue from the solder joints and the gauge jumper wires using a degreasing solvent and a soft brush.
5. Record the resistance of each gauge at the wiring terminals. Compare this to the resistances recorded in Step 1. This will confirm the integrity of the jumper wires and the solder joints at the gauge and the terminals.
6. All strain gauge wiring for balances should be subjected to an insulation resistance test by submerging the wire in regular tap water and measuring the leakage to ground resistance. This resistance should be greater than 10 Gig-ohms.
7. All interconnecting wiring (wiring between gauges and between balance components) must be carefully stripped and tinned prior to installing at its respective terminal. Inspect for anomalies in the insulation and nicks in the strands before tinning.
8. When possible, all interconnecting wiring between gauges in a bridge should be of equal resistance and length.
9. All interconnecting wiring for a given bridge should be snug against the balance surfaces along the entire length of the wire. Do not allow any wiring to span open areas within the balance. When wiring a balance designed for light loads, care must be exercised in preventing the wires from carrying any part of the load that's being applied to the measuring beams. Later, when applying the moisture-proofing, do not allow the moisture-proofing to bond the wiring to the load-carrying (measuring) beams.
10. Wire routing should be preplanned with no wiring routed over the strain gauge active grids or the gauge jumpers.
11. When all wiring is completed the balance should be cleaned to remove all soldering residues and other foreign matter.

<u>Initial Electrical Checks</u>

1. Check the balance components to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be greater than 10 Gig-ohms.
2. Record the bridge electrical zeros. Bridge excitation voltage should be the same as that to be used for the balance when in service. For each balance component, check to confirm that the zero is representative of the arbitrary differences in the resistances of the four gauges that comprise the bridge circuit. The zeros should be within ±0.4mV/V of the calculated zero. This agreement may be harder to achieve on smaller balances where lightly loaded beams and small interconnecting wiring can affect the calculated zero.
3. The tolerance allowable for the recorded electrical zeros for all components is quoted on the balance drawing. The typical allowance is ±0.4mV/V.

4. Mechanically shunt each gauge within a bridge while observing its electrical zero in order to verify the bridge integrity.
5. When possible, hand-load each component to verify expected sensitivity. Also, check for zero shifts as a function of loading and unloading the balance.

Elevated Temperature Soak Cycles

Prior to commencing apparent strain runs the newly wired balance is to be subjected to a series of thermal cycles as follows: With the balance supported as it will be for the apparent strain correction task, record the electrical zero of each component. Next, heat the balance to 250°F (the heat-up rate should not exceed 6°F/minute). Hold the balance at that temperature for 15 minutes, and then return the balance to room temperature. Repeat the thermal cycling to 250°F and back to room temperature two more times (a total of three thermal cycles). Compare the zeros with the zeros recorded prior to the thermal cycling. A large change in zero in a given component (>0.010mV/V) indicates a potential problem and the component should be investigated further to resolve the source of the zero change. Once the thermal cycling is satisfactorily completed, proceed with the apparent strain correction.

Apparent Strain Correction

Note: Apparent strain correction for this class of balances involves adding temperature-sensitive wire(s) to a given component in order to minimize the change in that component's electrical zero during the temperature excursion from room temperature to -275°F. It should be noted that this correction is made based on the component's zero at -275°F compared to its zero at room temperature. The apparent strain correction does not attempt to correct for changes in zero at discreet temperatures during the temperature excursion between room temperature and -275°F. However, corrections for "loop data" in the Axial component are facilitated during the apparent strain correction procedures.

1. Place the balance in the temperature chamber horizontally, in the –Normal Force up position, supported at the non-metric end only.
2. The balance should be covered with a non-contacting encasement uniformly constructed such that the balance is not directly exposed to any airflow.
3. Connect the balance to the data acquisition system including bridge excitation voltage. Allow this set-up to stabilize until the balance's PRT's read within 3°F of each other.
4. At the end of the warm-up period, start a "time versus output" recording at "room temperature" with the temperature chamber airflow on and the chamber temperature controller set at 75°F.
5. Continue recording the "room temperature" outputs until all component zeros are stable, i.e., not changing more than 0.001mV/5VDC/5 minutes. Arbitrarily choose one of the PRT's to be "the monitor PRT." The temperature of the monitor PRT should also be stable, i.e., not changing more than 0.2°F/minute. Record the actual temperature of the monitor PRT at this time.
6. Now commence the gas nitrogen purging. The rate for this nitrogen purge is typically 4.5SLPM.
7. Next, wait for the zeros to re-stabilize as in Step 5. On a worksheet, record these initial room temperature zeros and the temperature of the monitor PRT. Once Step 7 has been achieved, turn the temperature controller setting to -280°F and allow the balance to cool until a stable temperature, within three degrees of the -275°F target temperature, is indicated with all three of the PRT's. The PRT's must be within 3°F of each other.

8. Allow the balance to soak at the stabilized -275°F temperature until the drift rate of the electrical zero for each component does not exceed 0.005mV/5VDC/5 minutes.
9. Once the drift rate requirement at the -275°F target temperature is achieved, heat the balance to room temperature using the temperature chamber controller as necessary to bring the monitoring PRT temperature to the same temperature that was recorded in Step 7 within ±2°F.
10. <u>It is important</u> that the balance temperature be observed during the heat-up phase of the run and that <u>the power supply be turned off when the balance temperature reaches 0°F</u>.
11. On a worksheet, use the recorded apparent strain run to record the output of each component at -275°F with respect to the "initial room temperature" zero.
12. For each component requiring reduction of its apparent strain, add an appropriate amount of copper wire to the necessary arm(s) of the bridge circuit to nullify the apparent strain of the bridge. When possible, the correction wire should be added in equal amounts in the two appropriate arms of the bridge. The tolerance allowed for apparent strain is ±0.002mV/V/Δ100°F based on the average slope unless otherwise stated on the gauging drawing. Average slope is defined here as the slope generated from the midpoint between the initial zero at room temperature and the final zero at room temperature and the total output at -275°F.
13. Conduct another apparent strain run as per Step 1 through Step 12.
14. At this time, make the initial resistance adjustment of the Axial differential compensation sensors as the magnitude of "loop data" dictates.
15. Make another apparent strain run as per Steps 1 through 12. It may be necessary to adjust the value of the axial differential compensation sensors or the apparent strain correction resistances.
16. After verifying that the apparent strain outputs are within the specifications for all components, apply the moisture-barrier protective coating (procedure reviewed in next section) over gauge solder dots, gauge jumpers, solder joints, axial sensors, and uninsulated wiring as appropriate.
17. Conduct an initial "moisture-proofed" apparent strain run as per Step 1 through Step 11 to verify that all components are still within the specifications for apparent strain correction. Voltage is to be kept on all bridges for moisture-proofed apparent strain runs. If additional corrections are required, perform those corrections using the procedures in Step 11 and Step 12.
18. Conduct another apparent strain run as per Step 1 through Step 12.
19. Conduct another apparent strain run as per Step 1 through Step 12 except that when heating the balance following the excursion down to -275°F continue heating the balance up to 150°F before returning to room temperature. This run is made in order to verify repeatability of apparent strain outputs with moisture-barrier in place on the balance and to verify that the balance apparent strain outputs meet specifications for the entire operating range. All components are to be repeatable with respect to the previous run within ±0.002mV/V at any discreet point throughout the temperature excursion, not to exceed a total output of ±0.005mV/V at -275°F or at 150°F. NOTE: Voltage is to be kept on all bridges for moisture-proofed apparent strain runs.
20. Following verification that the apparent strain outputs are within the specifications as per Step 12 and Step 19, perform a final microscopic examination of the balance and record final electrical zeros and leakage to ground resistances. The balance should now be ready to be forwarded to the loading calibration laboratory.

Moisture-proofing Procedure

The procedure for moisture-proofing balances will necessarily vary depending on the size, design, and operational environment of the balance. The steps below are provided only as a "good practice" guide. All balances are to be coated in certain areas with a moisture-barrier coating and the coating is to be applied following the apparent strain run in Step 15 of the previous section. The moisture-barrier is to be type: N-1. Generally, it is to be applied as follows:

1. Flush the balance with an appropriate degreasing solution. Follow this with a flushing of 200 proof alcohol.
2. The balance is to be at a temperature between 74°F and 80°F during the coating applications.
3. Coat all gauge solder dots, gauge jumpers, solder joints, axial differential compensation sensors, and all uninsulated wiring with an initial coat of N-1. The coating thickness should be 0.005" to 0.007" thick.
4. Allow this coating to air dry for a minimum of 20 minutes at room temperature.
5. Apply a second coating over the first. This coating should overlap all edges of the first coating.
6. Allow this coating to air dry for a minimum of one hour at room temperature.
7. Return to Step 17 in the previous section.

Notes: On larger balances, additional N-1 can be used to keep interconnecting wiring in place on the balance surfaces. No moisture-proofing is to be applied over the active grid areas of the gauges.

APPLICATION CLASS II – STRAIN GAUGE INSTALLATION PROCEDURES FOR ALL LANGLEY-DESIGNED TRANSDUCERS (EXCEPT BALANCES)

INSTALLATION TYPE 1 – Langley-designed Transducers Operating in 0°F to 200°F Range

NOTE: The following materials and procedures are applicable for all Langley-designed transducers operating in the temperature range of 0°F to 200°F. Apparent strain corrections are made for the temperature range of 80°F to 180°F.

Gauging Materials (all materials that are an integral part of the transducer)

1. Gauge type: to be designated by design engineer, typically type: C-891113-A (Vishay Micro-Measurements)
2. Adhesive type for applying gauges: M-BOND 610 (Vishay Micro-Measurements); adhesive type for PRT's when required: EA-934 (Hysol)
3. Wiring Terminals type: CPF series (Vishay Micro-Measurements); size of transducer determines which size(s) to use
4. Insulation Pads for Apparent Strain Correction Wire and Zero Correction Wire when required, type: Kapton, 1-mil, etched
5. Gauge-to-Terminal Jumper Wire: single strand, AWG#40, silver-clad copper
6. Apparent Strain Correction Wire when required, type: Nickel, size and location(s) within the bridge determined by the design of the transducer and the amount required for correction

7. Zero Offset Correction Wire when required, type: Manganin (Vishay Micro-Measurements); size determined by amount required for correction
8. Interconnecting wiring between gauges and/or between bridges, Wire: typically, AWG#30(7-38), AWG#32(7-40), or AWG#36(7-44). This wiring consists of 7 strands of silver-clad copper wire with Teflon insulation. Transducer size will determine wire size. Some small transducers will require single conductor solid copper, AWG#40 or AWG#42.
9. Transducer to DAS Connector (either integrated into transducer housing or at end of exit leadwires): determined by design engineer, user facility dependant
10. Exit Leadwires (when used in lieu of integral connector): size and length determined by design engineer
11. Solder type: 361A (Vishay Micro-Measurements)
12. Thermocouples when required, type: "J", size typically AWG#36, with Teflon insulation
13. Platinum Resistance Thermometers (PRT's) when required, type: EL-700T (Hy-Cal)
14. Protective Coating over exposed solder joints and uninsulated wiring, typically, type: Gagekote #8 (Vishay Micro-Measurements)
15. Protective Sleeving over Exit Leadwires when required, type: nylon or fiberglass, determined by the design engineer

Surface Preparation for Gauging

1. Degrease the entire transducer. This is typically accomplished with a vapor degreasing solvent rinse, types: ENSOLV (Envirotech) or Hypersolve (Ecolink).
2. Perform microscopic examination of the transducer looking for flaws in surface, cracked beams, sharp edges, etc.
3. Rinse the entire transducer with ethyl alcohol 200 proof.
4. Mask appropriate areas of the transducer for micro-sandblasting operation.
5. Micro-sandblast areas to be gauged using 50 micron Al_2O_3 abrasive powder.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the solvent degreasing and alcohol rinse operations. Installation of the gauges should begin immediately following this step.

Installation of the Gauges

1. Gauges, pretrimmed wiring terminals, and insulation pads when used, should be cleaned with 200 proof alcohol, dried, and placed on a clean glass plate. They should be inverted with the undersides up and ready for application of the gauging adhesive.
2. Apply a coat of M-610 to the underside of the gauges, terminals, etc., as well as a coat to the appropriate transducer surfaces.
3. Allow the coated items to air dry at least ten minutes at room temperature (air temperature and transducer temperature to be no less than 72°F and relative humidity to be not more than 40 percent).
4. Place the gauges, terminals, etc., on the transducer surfaces at predetermined locations and cover with a thin, pressure-sensitive Teflon tape.
5. Next, place silicone rubber pads over the tape in the areas where the gauges, terminals, etc., are located.

6. Apply a constant and uniform pressure of 60psi to the rubber pads using an appropriate clamping device.
7. Place the transducer in a temperature chamber and slowly raise the temperature of the balance to 340°F. The heating rate should be approximately 6°F/minute.
8. Hold the transducer at this temperature for one hour, then, cool the transducer through simple convection means.
9. Once the transducer is cool, remove the clamping device, the rubber pads, and the tape. Microscopically, inspect the gauge installations for accuracy of gauge positioning and alignment, glue-line voids, or foreign matter. The tolerance for location of the gauge on the transducer is typically ±0.005" of the stated location as per the transducer strain gauge drawing unless otherwise stated.
10. Some transducers will require two or more cure cycles to install all of the gauges. The gauging areas that will require gauges during the subsequent curing cycles should be micro-sandblasted again, prior to each gauge installation operation, repeating the surface preparation steps previously outlined.
11. To post cure the gauge installations, slowly raise the temperature at the same heating rate used for the gauge installations until a transducer temperature of 340°F is reached. Hold the transducer at that temperature for two hours. Cool the transducer and repeat the microscopic inspection of the gauges.

Wiring the Transducer

Note: Because of the considerable variation in transducer design and size it is not possible to itemize and detail a standard wiring procedure for all Langley-designed transducers in this class. Nonetheless, certain steps can be detailed while others must be generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gauge (to the nearest hundredth of an ohm) at the gauge's solder dots.
2. Using a hard rubber eraser, remove the oxidation from the gauging terminals.
3. Install and solder the gauge jumpers between the gauge dots and the wiring terminals. All soldering for these transducers should be performed using the NASA soldering handbook titled, "NHB5300.4(3A-1)" as a guide.
4. Remove the flux residue from the solder joints and the gauge jumper wires using a degreasing solvent and a soft brush.
5. Record the resistance of each gauge at the wiring terminals. Compare this to the resistances recorded in Step 1. This will confirm the integrity of the jumper wires and the solder joints at the gauge and the terminals.
6. All strain gauge wiring for transducers should be subjected to an insulation resistance test by submerging the wire in regular tap water and measuring the leakage to ground resistance. This resistance should be greater than 10 Gig-ohms.
7. All interconnecting wiring (wiring between gauges and between transducer components for multi-channel transducers) must be carefully stripped and tinned prior to installing at its respective terminal. Inspect for anomalies in the insulation and nicks in the strands before tinning.
8. When possible, all interconnecting wiring between gauges in a bridge should be of equal resistance and length.

9. All interconnecting wiring for a given bridge should be snug against the transducer surfaces along the entire length of the wire. Do not allow any wiring to span open areas within the transducer. When wiring a transducer designed for light loads, care must be exercised in preventing the wires from carrying any part of the load that's being applied to the measuring beams. Later, when applying the moisture-proofing, do not allow the moisture-proofing to bond the wiring to the load-carrying (measuring) beams.
10. Wire routing should be preplanned with no wiring routed over the strain gauge active grids or the gauge jumpers.
11. When all wiring is completed the transducer should be cleaned to remove all soldering residues and other foreign matter.

Initial Electrical Checks

1. Check the transducer components to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be greater than 10 Gig-ohms.
2. Record the bridge electrical zeros. Bridge excitation voltage should be the same as that to be used for the transducer when in service. For each transducer component, check to confirm that the zero is representative of the arbitrary differences in the resistances of the four gauges that comprise the bridge circuit. The zeros should be within ±0.4mV/V of the calculated zero. This agreement may be harder to achieve on smaller transducers where lightly loaded beams and small interconnecting wiring can affect the calculated zero.
3. The tolerance allowable for the recorded electrical zeros for all components is quoted on the transducer drawing. The typical allowance is ±0.4mV/V.
4. Mechanically shunt each gauge within a bridge while observing its electrical zero in order to verify the bridge integrity.
5. When possible, hand-load each component to verify expected sensitivity. Also, check for zero shifts as a function of loading and unloading the transducer.

Elevated Temperature Soak Cycles

Prior to commencing apparent strain runs the newly wired transducer is to be subjected to a series of thermal cycles as follows: With the transducer supported as it will be for the apparent strain correction task, record the electrical zero of each component. Next, heat the transducer to 250°F (the heat-up rate should not exceed 6°F/minute). Hold the transducer at that temperature for 15 minutes, and then return the transducer to room temperature. Repeat the thermal cycling to 250°F and back to room temperature two more times (a total of three thermal cycles). Compare the zeros with the zeros recorded prior to the thermal cycling. A large change in zero in a given component (>0.010mV/V) indicates a potential problem and the component should be investigated further to resolve the source of the zero change. Once the thermal cycling is satisfactorily completed, proceed with the apparent strain correction.

Apparent Strain Correction

Note: Apparent strain correction for this class of transducers involves adding temperature-sensitive wire(s) to a given component in order to minimize the change in that component's electrical zero during the temperature excursion from room temperature to 180°F. It should be noted that this correction is made based on the component's zero at 180°F compared to its zero at room temperature. The apparent strain correction does not attempt to correct for changes in zero at discreet temperatures during the temperature excursion between room temperature and 180°F.

1. Place the transducer in the temperature chamber in a manner that will allow the transducer load beams to expand without constraint.
2. The transducer should be covered with a non-contacting encasement uniformly constructed such that the transducer is not directly exposed to any airflow.
3. For monitoring temperature during the run, attach a thermocouple to the transducer in an area as close to the load beam(s) as possible, using a piece of aluminum tape. If the transducer has it's own thermocouple or PRT, use it.
4. Connect the transducer to the data acquisition system including bridge excitation voltage (bridge voltage is to be the same as that which will be used for the complete transducer load calibration.)
5. Allow a 30-minute "warm-up" period with the transducer connected to the data acquisition system as in Step 4.
6. At the end of the 30-minute warm-up period, start a "time versus output" recording at "room temperature" with the temperature chamber airflow on and the chamber temperature controller set at 80°F.
7. Continue recording the "room temperature" outputs until all component zeros are stable, i.e., not changing more than 0.001mV/5VDC/5 minutes. The temperature of the monitor thermocouple (or PRT) should also be stable, i.e., not changing more than 0.2°F/minute. Record the actual temperature of the monitor thermocouple at this time.
8. Once Step 7 has been achieved, turn the temperature controller setting to 180°F and allow the transducer to heat until a stable temperature, within two degrees of the 180°F target temperature, is indicated with the monitoring thermocouple (or PRT) on the transducer. The heat-up rate should not exceed 6°F/minute. The temperature of the monitor thermocouple (or PRT) should also be stable, i.e., not changing more than 0.2°F/minute.
   Allow the transducer to soak at the elevated stabilized temperature until the drift rate of the electrical zero for each component does not exceed 0.001mV/5VDC/5 minutes.
9. Once the drift rate requirement at the 180°F target temperature is achieved, cool the transducer to room temperature using the temperature chamber controller as necessary to bring the monitoring thermocouple temperature to the same temperature that was recorded in Step 7 within ±1°F. Continue recording the "room temperature" outputs until all component zeros are stable, i.e., not changing more than 0.001mV/5VDC/5 minutes. The temperature of the monitor thermocouple (or PRT) should also be stable, i.e., not changing more than 0.2°F/minute. Record the actual temperature of the monitor thermocouple at this time.
10. On a worksheet, use the recorded apparent strain run to record the output of each component at 180°F with respect to the "return to room temperature" zero.
11. For each component requiring reduction of its apparent strain, add an appropriate amount of nickel wire to the necessary arm(s) of the bridge circuit to nullify the apparent strain of the bridge. When possible, the correction wire should be added in equal amounts in the two appropriate arms of the bridge. The tolerance allowed for apparent strain is ±0.003mV/V/Δ100°F based on the average slope unless otherwise stated on the gauging drawing. Average slope is defined here as the slope generated from the midpoint between the initial zero at room temperature and the final zero at room temperature and the total output at 180°F.
12. Conduct another apparent strain run as per Step 1 through Step 11.

13. After verifying that the apparent strain outputs are within the specifications for all components, apply the moisture-barrier protective coating (procedure reviewed in next section) over gauge solder dots, gauge jumpers, solder joints, and uninsulated wiring as appropriate.
14. Conduct an initial "moisture-proofed" apparent strain run as per Step 1 through Step 11 to verify that all components are still within the specifications for apparent strain correction. If additional corrections are required, perform those corrections using the procedures in Step 11 and Step 12.
15. Conduct another apparent strain run as per Step 1 through Step 11.
16. Conduct another apparent strain run as per Step 1 through Step 11 in order to verify repeatability of apparent strain outputs with moisture-barrier in place on the transducer. All components are to be repeatable with respect to the previous run within ±0.002mV/V at any discreet point throughout the temperature excursion, not to exceed a total output of ±0.003mV/V at 180°F.
17. Following verification that the apparent strain outputs are within the specifications as per Step 11 and Step 16, perform a final microscopic examination of the transducer and record final electrical zeros and leakage to ground resistances. The transducer should now be ready to be forwarded to the loading calibration laboratory.

<u>Moisture-proofing Procedure</u>

The procedure for moisture-proofing transducers will necessarily vary depending on the size, design, and operational environment of the transducer. The steps below are provided only as a "good practice" guide. All transducers are to be coated in certain areas with a moisture-barrier coating and the coating is to be applied following the apparent strain run in Step 12 of the previous section. The moisture-barrier is to be Gagekote #8. Generally, it is to be applied as follows:

1. Flush the transducer with an appropriate degreasing solution. Follow this with a flushing of 200 proof alcohol.
2. The transducer is to be at a temperature between 74°F and 80°F during the coating applications.
3. Coat all gauge solder dots, gauge jumpers, solder joints, and all uninsulated wiring with an initial coat of Gagekote #8. The coating thickness should be 0.005" to 0.007" thick.
4. Allow this coating to air dry for a minimum of 20 minutes at room temperature.
5. Apply a second coating over the first. This coating should overlap all edges of the first coating.
6. Allow this coating to air dry for a minimum of one hour at room temperature.
7. Return to Step 15 in the previous section.
   Notes: On larger transducers, additional Gagekote #8 can be used to keep interconnecting wiring in place on the transducer surfaces. When practical, no moisture-proofing is to be applied over the active grid areas of the gauges.

INSTALLATION TYPE 2 – Langley-designed Transducers Operating in -275°F to 200°F Range

NOTE: The following materials and procedures are applicable for typical Langley transducers operating at temperatures between –275°F and 200°F. Apparent strain corrections are made for that temperature range.

Gauging Materials (all materials that are an integral part of the transducer)

1. Gauge type: to be designated by design engineer, typically type: C-891113-B (Vishay Micro-Measurements)
2. Adhesive type for applying gauges: M-BOND 610 (Vishay Micro-Measurements); adhesive type for PRT's when required: EA-934 (Hysol)
3. Wiring Terminals type: CPF series (Vishay Micro-Measurements); size of transducer determines which size(s) to use
4. Insulation Pads for Apparent Strain Correction Wire and Zero Correction Wire when required, type: Kapton, 1-mil, etched
5. Gauge-to-Terminal Jumper Wire: single strand, AWG#40, silver-clad copper
6. Apparent Strain Correction Wire when required, type: silver-clad copper, size and location(s) within the bridge determined by the design of the transducer and the amount required for correction
7. Platinum Resistance Thermometers (PRT's) when required, type: EL-700T (Hy-Cal)
8. Interconnecting wiring between gauges and/or between bridges, Wire: typically, AWG#30(7-38), AWG#32(7-40), or AWG#36(7-44). This wiring consists of 7 strands of silver-clad copper wire with "etched" Teflon insulation. Transducer size will determine wire size
9. Solder type: 361A (Vishay Micro-Measurements)
10. Protective Coating over exposed solder joints and uninsulated wiring, typically, type: N-1 (Texas Measurements)
11. Transducer Connector (when used), type determined by design engineer
12. Sealant between connector and transducer housing, type: RTV-3140 (Dow-Corning)

Surface Preparation for Gauging

1. Degrease the entire transducer. This is typically accomplished with a vapor degreasing solvent rinse, types: ENSOLV (Envirotech) or Hypersolve (Ecolink).
2. Perform microscopic examination of the transducer looking for flaws in surface, cracked beams, sharp edges, etc.
3. Rinse the entire transducer with ethyl alcohol 200 proof.
4. Mask appropriate areas of the transducer for micro-sandblasting operation.
5. Micro-sandblast areas to be gauged using 50 micron Al_2O_3 abrasive powder.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the solvent degreasing and alcohol rinse operations. Installation of the gauges should begin immediately following this step.

Installation of the Gauges

Note: Gauges to be installed on cryogenic transducers must first be "matched" for apparent strain considerations. A FSIS Memorandum to Technical Files titled, "Matching Cryogenic Strain Gauges," dated April 18, 1994, details the procedure to be utilized for matching strain gauges for cryogenic balances. That particular memorandum is included with this document, at the end of the text, as Addendum #1. All strain gauges to be applied to NASA Langley cryogenic transducers must first be "matched" using the above referenced technical memorandum.

1. At this point, the matched gauges have been cleaned, cataloged, and placed in their respective

pockets in a custom gauge organizer. Pretrimmed wiring terminals, and insulation pads when used, should be cleaned with 200 proof alcohol, dried, and placed on a clean glass plate along with the appropriate gauges. They should be inverted with the undersides up and ready for application of the gauging adhesive.

2. Apply a coat of M-610 to the underside of the gauges, terminals, etc., as well as a coat to the appropriate transducer surfaces.
3. Allow the coated items to air dry at least ten minutes at room temperature (air temperature and transducer temperature to be no less than 72°F and relative humidity to be not more than 40 percent).
4. Place the gauges, terminals, etc., on the transducer surfaces at predetermined locations and cover with a thin, pressure-sensitive Teflon tape.
5. Next, place silicone rubber pads over the tape in the areas where the gauges, terminals, etc., are located.
6. Apply a constant and uniform pressure of 60psi to the rubber pads using an appropriate clamping device.
7. Place the transducer in a temperature chamber and slowly raise the temperature of the transducer to 340°F. The heating rate should be approximately 6°F/minute.
8. Hold the transducer at this temperature for one hour, then, cool the transducer through simple convection means.
9. Once the transducer is cool, remove the clamping device, the rubber pads, and the tape. Microscopically, inspect the gauge installations for accuracy of gauge positioning and alignment, glue-line voids, or foreign matter. The tolerance for location of the gauge on the transducer is typically ±0.005" of the stated location as per the transducer strain gauge drawing unless otherwise stated.
10. Some transducers will require two or more cure cycles to install all of the gauges. The gauging areas that will require gauges during the subsequent curing cycles should be micro-sandblasted again, prior to each gauge installation operation, repeating the surface preparation steps previously outlined.
11. To post cure the gauge installations, slowly raise the temperature at the same heating rate used for the gauge installations until a transducer temperature of 340°F is reached. Hold the transducer at that temperature for two hours. Cool the transducer and repeat the microscopic inspection of the gauges.

Wiring the Transducer

Note: Because of the considerable variation in transducer design and size it is not possible to itemize and detail a standard wiring procedure for all Langley transducers in this class. Nonetheless, certain steps can be detailed while others must be generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gauge (to the nearest hundredth of an ohm) at the gauge's solder dots.
2. Using a hard rubber eraser, remove the oxidation from the gauging terminals.
3. Install and solder the gauge jumpers between the gauge dots and the wiring terminals. All soldering for these transducers should be performed using the NASA soldering handbook titled, "NHB 5300.4(3A-1)" as a guide.

4. Remove the flux residue from the solder joints and the gauge jumper wires using a degreasing solvent and a soft brush.
5. Record the resistance of each gauge at the wiring terminals. Compare this to the resistances recorded in Step 1. This will confirm the integrity of the jumper wires and the solder joints at the gauge and the terminals.
6. All strain gauge wiring for tranducers should be subjected to an insulation resistance test by submerging the wire in regular tap water and measuring the leakage to ground resistance. This resistance should be greater than 10 Gig-ohms.
7. All interconnecting wiring (wiring between gauges and between balance components) must be carefully stripped and tinned prior to installing at its respective terminal. Inspect for anomalies in the insulation and nicks in the strands before tinning.
8. When possible, all interconnecting wiring between gauges in a bridge should be of equal resistance and length.
9. All interconnecting wiring for a given bridge should be snug against the transducer surfaces along the entire length of the wire. Do not allow any wiring to span open areas within the transducer. When wiring a transducer designed for light loads, care must be exercised in preventing the wires from carrying any part of the load that's being applied to the measuring beams. Later, when applying the moisture-proofing, do not allow the moisture-proofing to bond the wiring to the load-carrying (measuring) beams.
10. Wire routing should be preplanned with no wiring routed over the strain gauge active grids or the gauge jumpers.
11. When all wiring is completed the transducer should be cleaned to remove all soldering residues and other foreign matter.

Initial Electrical Checks

1. Check the transducer component(s) to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be greater than 10 Gig-ohms.
2. Record the bridge electrical zeros. Bridge excitation voltage should be the same as that to be used for the transducer when in service. For each transducer component, check to confirm that the zero is representative of the arbitrary differences in the resistances of the four gauges that comprise the bridge circuit. The zeros should be within ±0.4mV/V of the calculated zero. This agreement may be harder to achieve on smaller transducers where lightly loaded beams and small interconnecting wiring can affect the calculated zero.
3. The tolerance allowable for the recorded electrical zeros for all components is quoted on the transducer drawing. The typical allowance is ±0.4mV/V.
4. Mechanically shunt each gauge within a bridge while observing its electrical zero in order to verify the bridge integrity.
5. When possible, hand-load each component to verify expected sensitivity. Also, check for zero shifts as a function of loading and unloading the transducer.

Elevated Temperature Soak Cycles

Prior to commencing apparent strain runs the newly wired transducer is to be subjected to a series of thermal cycles as follows: With the transducer supported as it will be for the apparent strain correction task, record the electrical zero of each component. Next, heat the transducer to 250°F (the heat-up rate should not exceed 6°F/minute). Hold the transducer at that temperature for 15 minutes, and then return the transducer to room temperature. Repeat the thermal cycling to 250°F and back to room temperature two more times (a total of three thermal cycles). Compare the zeros with the zeros recorded prior to the thermal cycling. A large change in zero in a given component (>0.010mV/V) indicates a potential problem and the component should be investigated further to resolve the source of the zero change. Once the thermal cycling is satisfactorily completed, proceed with the apparent strain correction.

Apparent Strain Correction

Note: Apparent strain correction for this class of transducers involves adding temperature-sensitive wire(s) to a given component in order to minimize the change in that component's electrical zero during the temperature excursion from room temperature to -275°F. It should be noted that this correction is made based on the component's zero at -275°F compared to its zero at room temperature. The apparent strain correction does not attempt to correct for changes in zero at discreet temperatures during the temperature excursion between room temperature and -275°F.

1. Place the transducer in the temperature chamber in a manner that will allow the transducer load beams to expand without constraint.
2. The transducer should be covered with a non-contacting encasement uniformly constructed such that the transducer is not directly exposed to any airflow.
3. For monitoring temperature during the run, attach a thermocouple to the transducer in an area as close to the load beam(s) as possible, using a piece of aluminum tape. If the transducer has it's own thermocouple or PRT, use it.
4. Connect the transducer to the data acquisition system including bridge excitation voltage (bridge voltage is to be the same as that which will be used for the complete transducer load calibration). Allow this set-up to stabilize for several minutes.
5. When the zero(s) is stable, i.e., drift rate is <0.001mV/5VDC/5 minutes, commence a gas nitrogen purging of the area(s) of the transducer containing the strain gauges and wiring. The design of the transducer will determine the manner in which purging is accomplished. The rate for the nitrogen purge is typically 4.5SLPM.
   NOTE: Gas nitrogen purging is to be used for <u>all</u> of the apparent strain runs with Langley-designed transducers.
6. With the nitrogen purging underway, wait for the zero(s) to re-stabilize as per the drift rate in Step 5. On a worksheet, record the initial room temperature zero(s) and the temperature of the monitor thermocouple or PRT.
7. Once Step 6 has been achieved, turn the temperature controller setting to -280°F and allow the transducer to cool until a stable temperature, within three degrees of the -275°F target temperature, is indicated with the monitor thermocouple.
8. Allow the transducer to soak at the stabilized -275°F temperature until the drift rate of the electrical zero for each component does not exceed 0.005mV/5VDC/5 minutes.
9. Once the drift rate requirement at the -275°F target temperature is achieved, heat the transducer to room temperature using the temperature chamber controller as necessary to bring the monitoring thermocouple temperature to the same temperature that was recorded in Step 6 within ±2°F.
10. <u>It is important</u> that the transducer temperature be observed during the heat-up phase of the run and that <u>the power supply be turned off when the transducer temperature reaches 0°F</u>.

11. On a worksheet, use the recorded apparent strain run to record the output of each component at -275°F with respect to the "initial room temperature" zero.
12. For each component requiring reduction of its apparent strain, add an appropriate amount of copper wire to the necessary arm(s) of the bridge circuit to nullify the apparent strain of the bridge. When possible, the correction wire should be added in equal amounts in the two appropriate arms of the bridge. The tolerance allowed for apparent strain is ±0.002mV/V/Δ100°F based on the average slope unless otherwise stated on the gauging drawing. Average slope is defined here as the slope generated from the midpoint between the initial zero at room temperature and the final zero at room temperature and the total output at -275°F.
13. Conduct another apparent strain run as per Step 1 through Step 11.
14. After verifying that the apparent strain output(s) is within the specifications, apply the moisture-barrier protective coating (procedure reviewed in next section) over gauge solder dots, gauge jumpers, solder joints, and uninsulated wiring as appropriate.
15. Conduct an initial "moisture-proofed" apparent strain run as per Step 1 through Step 11 to verify that all components are still within the specifications for apparent strain correction. Voltage is to be kept on all bridges for moisture-proofed apparent strain runs. If additional corrections are required, perform those corrections using the procedures in Step 11 and Step 12.
16. Conduct another apparent strain run as per Step 1 through Step 11.
17. Conduct another apparent strain run as per Step 1 through Step 11 except that when heating the transducer following the excursion down to -275°F continue heating the transducer up to 200°F before returning to room temperature. This run is made in order to verify repeatability of apparent strain outputs with moisture-barrier in place on the transducer and to verify that the transducer apparent strain outputs meet specifications for the entire operating range. All components are to be repeatable with respect to the previous run within +/-0.002mV/V at any discreet point throughout the temperature excursion, not to exceed a total output of +/-0.005mV/V at -275°F or at 200°F.

    NOTE: Voltage is to be kept on all bridges for moisture-proofed apparent strain runs.
18. Following verification that the apparent strain outputs are within the specifications as per Step 12 and Step 17, perform a final microscopic examination of the transducer and record final electrical zero(s) and leakage to ground resistances. The transducer should now be ready to be forwarded to the loading calibration laboratory.

Moisture-proofing Procedure

The procedure for moisture-proofing transducers will necessarily vary depending on the size, design, and operational environment of the transducer. The steps below are provided only as a "good practice" guide. All transducers are to be coated in certain areas with a moisture-barrier coating and the coating is to be applied following the apparent strain run in Step 15 of the previous section. The moisture-barrier is to be type: N-1. Generally, it is to be applied as follows:

1. Flush the transducer with an appropriate degreasing solution. Follow this with a flushing of 200 proof alcohol.
2. The transducer is to be at a temperature between 74°F and 80°F during the coating applications.
3. Coat all gauge solder dots, gauge jumpers, solder joints, and all uninsulated wiring with an initial coat of N-1. The coating thickness should be 0.005" to 0.007" thick.
4. Allow this coating to air dry for a minimum of 20 minutes at room temperature.

5. Apply a second coating over the first. This coating should overlap all edges of the first coating.
6. Allow this coating to air dry for a minimum of one hour at room temperature.
7. Return to Step 17 in the previous section.

Notes: On larger transducers, additional N-1 can be used to keep interconnecting wiring in place on the transducer surfaces. No moisture-proofing is to be applied over the active grid areas of the gauges.

INSTALLATION TYPE 3 – Langley-designed Transducers Operating in 200°F to 450°F Range

NOTE: The following materials and procedures are applicable for typical Langley transducers operating at temperatures between 200° and 450°. Apparent strain corrections are made for the temperature range of 80° to 450°.

<u>Gauging Materials (all materials that are an integral part of the transducer)</u>

1. Gauge type: to be designated by design engineer, typically type: J5K-06-S104P-350/DP (Vishay Micro-Measurements)
2. Adhesive type for applying gauges: M-BOND 450 (Vishay Micro-Measurements)
3. Adhesive type for bonding thermocouples or PRT's when required: Omegabond 200 (Omega)
4. Wiring Terminals type: CPF series (Vishay Micro-Measurements); size of transducer determines which size(s) to use
5. Insulation Pads for Apparent Strain Correction Wire and Zero Correction Wire when required, type: Kapton, 1-mil, etched
6. Gauge-to-Terminal Jumper Wire: single strand, AWG#40, silver-clad copper
7. Apparent Strain Correction Wire when required, type: nickel, size and location(s) within the bridge determined by the design of the transducer and the amount required for correction
8. Platinum Resistance Thermometers (PRT's) when required, type: EL-700T (Hy-Cal)
9. Interconnecting wiring between gauges and/or between bridges, Wire: typically, AWG#30(7-38), AWG#32(7-40), or AWG#36(7-44). This wiring consists of 7 strands of silver-clad copper wire with "etched" Teflon insulation. Transducer size will determine wire size
10. Solder type: 570-28R (Vishay Micro-Measurements)
11. Protective Gauge Coating type: RTV-3140 (Dow-Corning)
12. Protective Sleeving over Exit Leadwires, type: Fiberglass (Varflex Corp.)

<u>Surface Preparation for Gauging</u>

1. Degrease the entire transducer. This is typically accomplished with a vapor degreasing solvent rinse, types: ENSOLV (Envirotech) or Hypersolve (Ecolink).
2. Perform microscopic examination of the transducer looking for flaws in surface, cracked beams, sharp edges, etc.
3. Rinse the entire transducer with ethyl alcohol 200 proof.
4. Mask appropriate areas of the transducer for micro-sandblasting operation.
5. Micro-sandblast areas to be gauged using 50 micron Al_2O_3 abrasive powder.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the solvent degreasing and alcohol rinse operations. Installation of the gauges should begin immediately following this step.

Installation of the Gauges

All gauges are to be installed as per a Vishay-Micro-Measurements Group document published in 1990 titled, “Instructions for the Application of Micro-Measurments M-Bond 450 Adhesive.” It should be noted that Step 4 of that document includes the use of MJG-2 Mylar tape. It is recommended that “Type C Teflon Tape” (Connecticut Hard Rubber, Inc.) be used in place of that tape. Two additional recommendations are that the clamping pressure be set at 50psi and that the post cure temperature for the installed gauges be set at 50°F higher than the maximum operating temperature for the transducer being instrumented.

Wiring the Transducer

Note: Because of the considerable variation in transducer design and size it is not possible to itemize and detail a standard wiring procedure for all Langley transducers in this class. Nonetheless, certain steps can be detailed while others must be generalized. The steps below are provided only as a “good practice” guide.

1. On a worksheet, record the resistance of each gauge (to the nearest hundredth of an ohm) at the gauge’s solder dots.
2. Using a hard rubber eraser, remove the oxidation from the gauging terminals.
3. Install and solder the gauge jumpers between the gauge dots and the wiring terminals. All soldering for these transducers should be performed using the NASA soldering handbook titled, “NHB 5300.4(3A-1)” as a guide.
4. Remove the flux residue from the solder joints and the gauge jumper wires using a degreasing solvent and a soft brush.
5. Record the resistance of each gauge at the wiring terminals. Compare this to the resistances recorded in Step 1. This will confirm the integrity of the jumper wires and the solder joints at the gauge and the terminals.
6. All strain gauge wiring for transducers should be subjected to an insulation resistance test by submerging the wire in regular tap water and measuring the leakage to ground resistance. This resistance should be greater than 10 Gig-ohms.
7. All interconnecting wiring (wiring between gauges and between balance components) must be carefully stripped and tinned prior to installing at its respective terminal. Inspect for anomalies in the insulation and nicks in the strands before tinning.
8. When possible, all interconnecting wiring between gauges in a bridge should be of equal resistance and length.
9. All interconnecting wiring for a given bridge should be snug against the transducer surfaces along the entire length of the wire. Do not allow any wiring to span open areas within the transducer. When wiring a transducer designed for light loads, care must be exercised in preventing the wires from carrying any part of the load that’s being applied to the measuring beams. Later, when applying the moisture-proofing, do not allow the moisture-proofing to bond the wiring to the load-carrying (measuring) beams.
10. Wire routing should be preplanned with no wiring routed over the strain gauge active grids or the gauge jumpers.

11. When all wiring is completed the transducer should be cleaned to remove all soldering residues and other foreign matter.

Initial Electrical Checks

1. Check the transducer component(s) to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be greater than 10 Gig-ohms.
2. Record the bridge electrical zeros. Bridge excitation voltage should be the same as that to be used for the transducer when in service. For each transducer component, check to confirm that the zero is representative of the arbitrary differences in the resistances of the four gauges that comprise the bridge circuit. The zeros should be within ±0.4mV/V of the calculated zero. This agreement may be harder to achieve on smaller transducers where lightly loaded beams and small interconnecting wiring can affect the calculated zero.
3. The tolerance allowable for the recorded electrical zeros for all components is quoted on the transducer drawing. The typical allowance is ±0.4mV/V.
4. Mechanically shunt each gauge within a bridge while observing its electrical zero in order to verify the bridge integrity.
5. When possible, hand-load each component to verify expected sensitivity. Also, check for zero shifts as a function of loading and unloading the transducer.

Elevated Temperature Soak Cycle

Prior to commencing apparent strain runs the newly wired transducer is to be subjected to a series of thermal cycles as follows: With the transducer supported as it will be for the apparent strain correction task, record the electrical zero of each component. Next, heat the transducer to 450°F (the heat-up rate should not exceed 6°F/minute). Hold the transducer at that temperature for 15 minutes, and then return the transducer to room temperature. Repeat the thermal cycling to 450°F and back to room temperature two more times (a total of three thermal cycles). Compare the zeros with the zeros recorded prior to the thermal cycling. A large change in zero in a given component (>0.010mV/V) indicates a potential problem and the component should be investigated further to resolve the source of the zero change. Once the thermal cycling is satisfactorily completed, proceed with the apparent strain correction.

Apparent Strain Correction

Note: Apparent strain correction for this class of transducers involves adding temperature-sensitive wire(s) to a given component in order to minimize the change in that component's electrical zero during the temperature excursion from room temperature to 450°F. It should be noted that this correction is made based on the component's zero at 450°F compared to its zero at room temperature. The apparent strain correction does not attempt to correct for changes in zero at discreet temperatures during the temperature excursion between room temperature and 450°F.

1. Place the transducer in the temperature chamber in a manner that will allow the transducer load beams to expand without constraint.
2. The transducer should be covered with a non-contacting encasement uniformly constructed such that the transducer is not directly exposed to any airflow.

3. For monitoring temperature during the run, attach a thermocouple to the transducer in an area as close to the load beam(s) as possible, using a piece of aluminum tape. If the transducer has it's own thermocouple or PRT, use it.
4. Connect the transducer to the data acquisition system including bridge excitation voltage (bridge voltage is to be the same as that which will be used for the complete transducer load calibration.)
5. Allow a 30-minute "warm-up" period with the transducer connected to the data acquisition system as in Step 4.
6. At the end of the 30-minute warm-up period, start a "time versus output" recording at "room temperature" with the temperature chamber airflow on and the chamber temperature controller set at 80°F.
7. Continue recording the "room temperature" output(s) until all component zeros are stable, i.e., not changing more than 0.001mV/5VDC/5 minutes. The temperature of the monitor thermocouple (or PRT) should also be stable, i.e., not changing more than 0.2°F/minute. Record the actual temperature of the monitor thermocouple at this time.
8. Once Step 7 has been achieved, turn the temperature controller setting to 450°F and allow the transducer to heat until a stable temperature, within ten degrees of the 450°F target temperature, is indicated with the monitoring thermocouple (or PRT) on the transducer. The heat-up rate should not exceed 8°F/minute. The temperature of the monitor thermocouple (or PRT) should also be stable, i.e., not changing more than 0.5°F/minute. Allow the transducer to soak at the elevated stabilized temperature until the drift rate of the electrical zero for each component does not exceed 0.005mV/5VDC/5 minutes.
9. Once the drift rate requirement at the 450°F target temperature is achieved, cool the transducer to room temperature using the temperature chamber controller as necessary to bring the monitoring thermocouple temperature to the same temperature that was recorded in Step 7 within ±3°F. Continue recording the "room temperature" outputs until all component zeros are stable, i.e., not changing more than 0.001mV/5VDC/5 minutes. The temperature of the monitor thermocouple (or PRT) should also be stable, i.e., not changing more than 0.2°F/minute. Record the actual temperature of the monitor thermocouple at this time.
10. On a worksheet, use the recorded apparent strain run to record the output of each component at 450°F with respect to the "return to room temperature" zero.
11. For each component requiring reduction of its apparent strain, add an appropriate amount of nickel wire to the necessary arm(s) of the bridge circuit to nullify the apparent strain of the bridge. When possible, the correction wire should be added in equal amounts in the two appropriate arms of the bridge. The tolerance allowed for apparent strain is ±0.003mV/V/Δ100°F based on the average slope unless otherwise stated on the gauging drawing. Average slope is defined here as the slope generated from the midpoint between the initial zero at room temperature and the final zero at room temperature and the total output at 450°F.
12. Conduct another apparent strain run as per Step 1 through Step 12.
13. After verifying that the apparent strain outputs are within the specifications for all components, apply the moisture-barrier protective coating (procedure reviewed in next section) over gauge solder dots, gauge jumpers, solder joints, and uninsulated wiring as appropriate.
14. Conduct an initial "moisture-proofed" apparent strain run as per Step 1 through Step 11 to verify that all components are still within the specifications for apparent strain correction. If additional corrections are required, perform those corrections using the procedures in Step 11 and Step 12.
15. Conduct another apparent strain run as per Step 1 through Step 11.

16. Conduct another apparent strain run as per Step 1 through Step 11 in order to verify repeatability of apparent strain outputs with moisture-barrier in place on the transducer. All components are to be repeatable with respect to the previous run within ±0.003mV/V at any discreet point throughout the temperature excursion, not to exceed a total output of ±0.010mV/V at 450°F.
17. Following verification that the apparent strain outputs are within the specifications as per Step 12 and Step 17, perform a final microscopic examination of the transducer and record final electrical zeros and leakage to ground resistances. The transducer should now be ready to be forwarded to the loading calibration laboratory.

Moisture-proofing Procedure

The procedure for moisture-proofing transducers will necessarily vary depending on the size, design, and operational environment of the transducer. The steps below are provided only as a "good practice" guide. All transducers are to be coated in certain areas with a moisture-barrier coating and the coating is to be applied following the apparent strain run in Step 12 of the previous section. The moisture-barrier is to be RTV-3140. Generally, it is to be applied as follows:

1. Flush the transducer with an appropriate degreasing solution. Follow this with a flushing of 200 proof alcohol.
2. The transducer is to be at a temperature between 74°F and 80°F during the coating applications.
3. Coat all gauge solder dots, gauge jumpers, solder joints, and all uninsulated wiring with an initial application of RTV-3140. The coating thickness should be 0.020" to 0.030".
4. Allow this coating to air dry overnight at room temperature.
5. Return to Step 15 in the previous section.
   Notes: On larger transducers, additional RTV-3140 can be used to keep interconnecting wiring in place on the transducer surfaces. When practical, no moisture-proofing is to be applied over the active grid areas of the gauges.

APPLICATION CLASS III – STRAIN GAUGE INSTALLATION PROCEDURES FOR CERTAIN COMPOSITE MATERIALS

INSTALLATION TYPE 1 – Carbon or Glass/Epoxy Composites for Room Temperature Testing

NOTES: The following materials and procedures are applicable for gauging epoxy-based composites for test article structural analysis or materials properties testing at room temperature. Included in this installation type are composites that may or may not have a polymer added to the epoxy.

Gauging Materials (all materials that are an integral part of the strain-gauged composite

1. Gauge type: to be designated by test engineer, typically CEA series (Vishay Micro-Measurements)
2. Adhesive type: M-Bond GA-2 or M-Bond 200 (Vishay Micro-Measurements) – See "**Installation of the Gauges**" note following the section "**Surface Preparation for Gauging**"

3. Strain Gauge Leadwires, type and length: specified by test engineer; typically wiring is a 3-conductor flat ribbon, size AWG#30, stranded, tinned copper with a vinyl insulation over each conductor
4. Solder type: 361-A (Vishay Micro-Measurements)
5. Protective Gauge Coating when required, type: M-Coat A (Vishay Micro-Measurements)
6. Lead wire hold-down, typically, aluminum tape strips, type: FA-2 (Vishay Micro-Measurements), or silicone rubber, type: 3145-RTV (Vishay Micro-Measurements)
   NOTE: Depending on the testing conditions, both may be used in an alternating manner along the lead wire route.

Surface Preparation for Gauging Including Surface Basecoating When Required

1. Degrease and clean the surface(s) to be gauged. This is typically accomplished with a vapor degreasing solvent rinse, types: ENSOLV (Envirotech) or Hypersolve (Ecolink).
2. Perform a visual examination (microscopic when possible) of the areas to be gauged and the test article in general, looking for flaws in surface, i.e., delamination, cracks, broken fibers, voids, sharp edges, etc.
3. Rinse the areas to be gauged with ethyl alcohol 200 proof.
4. Mask appropriate areas of the test article for micro-sandblasting operation.
5. Micro-sandblast areas to be gauged using 50 micron Al_2O_3 abrasive powder. When micro-sandblasting is not possible, use hand-sanding with 220 grit silicon-carbide abrasive paper.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the solvent degreasing and alcohol rinse operations.

Note: Epoxy-based composites can be porous or quite rough or both. When either is encountered, a surface basecoat should be applied in the areas to be gauged. Following are steps for surface basecoating prior to the actual gauging process.

8. Apply a liberal coat of M-Bond GA-2 adhesive to the sandblasted areas with a thickness sufficient enough to cover the peaks of the rough surface.
9. On flat surfaces this M-Bond GA-2 adhesive basecoat can be left to dry as is. On surfaces where sag or runoff is a concern, place a Teflon film pad over the basecoat, install a vacuum applicator pad over the Teflon, and apply vacuum to the applicator pad.
10. Cure the test article for 4 hours at a minimum temperature of 100°F. An acceptable alternative cure would be to cure the test article for 2 hours at 125°F. If there is no allowance for heating the test article as above, then, the basecoat must be cured overnight at a minimum temperature of 80°F.
11. Once the basecoat is cured, it should be abraded until a uniformly textured surface is obtained. This hand-sanding operation should be performed using 220 grit silicon-carbide paper removing only an amount of the GA-2 sufficient to expose the fiber surface peaks.
12. Clean the basecoated areas once more with the alcohol.

Installation of the Gauges

Note: The following strain gauge installation procedure is applicable for long-term testing of the test article being instrumented. If it can be determined with certainty that the test article being gauged will be maintained in a temperature and humidity-controlled environment, then, M-Bond 200 adhesive can be substituted for the M-Bond GA-2 adhesive approach. For porous or rough composite surfaces, the basecoating operation would still be needed. The gauging procedure to be followed when using the M-Bond 200 adhesive is offered by Vishay Micro-Measurements, Inc. in their product catalog under the section titled, "TECH TIPS." The appropriate Tech Tip is titled, "Instruction Bulletin B-127-13." The following steps are applicable for gauging this class of composites using M-Bond GA-2 adhesive.

1. Areas to be gauged should be cleaned once again with 200 proof alcohol.
2. Make alignment marks in the appropriate location on test article surface (or along the edges of the GA-2 basecoat if used) such that they will align just outside the alignment marks around the four sides of the strain gauge backing.
3. The gauge to be installed is placed on a clean glass plate, underside down. A piece of Teflon tape (CHR, Inc. type C) is then applied to the topside of the gauge.
4. Next, transfer the gauge to the test article and position it in the area where the gauge alignment marks have been made.
5. Then lift the gauge up at one end using the Teflon tape. Fold the gauge back such that the underside of the gauge is up.
6. Brush a layer of M-Bond GA-2 adhesive onto the underside of the gauge and onto the surface to be gauged. Again, this surface may actually be a basecoat of the M-Bond GA-2.
7. When the appropriate viscosity of the M-Bond GA-2 is realized, lift the gauge again using the tape and place it back in position on the composite surface. It will, of course, be mated with the M-Bond GA-2 already on the surface.
   Note: If the viscosity of the M-Bond GA-2 is too thin or too viscous, glue-line voids or non-uniform glue-line thickness could occur. A rule-of-thumb for this type of application is that the viscosity is ideal at about one-half of the working pot life of the mixed adhesive.
8. Now, apply a uniform pressure of 10psi to 15psi to the gauge installation. A parallel bar clamp arrangement with a silicone rubber pad or a vacuum pad device can be used for maintaining pressure on the installation during the adhesive curing process.
9. Cure the installation at 100°F for four hours or at 125°F for two hours. If the test article is not allowed to be heated, then, the installation must be cured overnight at a minimum temperature of 80°F.
10. Following the adhesive cure cycle, remove the pressure applicator and the Teflon tape. Inspect the installation for voids, uneven glue-line, and gauge alignment. Because this procedure applies to room temperature testing only, no post curing of the installation is necessary.

Wiring the Gauge

Note: Because of the considerable variation in gauge construction and size it is not possible to itemize and detail a standard wiring procedure for all Langley gauge installations in this "installation type." Nonetheless, certain steps can be detailed while others must be generalized. The steps below are provided only as a “good practice” guide.

1. On a worksheet, record the resistance of each gauge (to the nearest hundredth of an ohm) at the gauge’s solder tabs.
2. Using a hard rubber eraser, remove the oxidation from the gauge terminals.
3. Apply solder the gauge terminals. All soldering for this type of installation should be performed using the NASA soldering handbook titled, “NHB 5300.4(3A-1)” as a guide.
4. Remove the flux residue from the soldered areas using a degreasing solvent and a soft brush.
5. Record the resistance of each gauge again at the solder tabs. Compare this to the resistances recorded in Step 1. This will confirm the integrity of the solder at the gauge tabs.
6. Strip both ends of the strain gauge leadwires and inspect for nicks in the strands. Tin the wires.
7. Position the leadwires at the end of the gauge and provide a mechanical strain relief in the leadwires near the gauge.
8. Secure the leadwires to the surface of the test article and solder the wires to the gauge solder tabs.
9. Remove the flux residue from the soldered areas using a degreasing solvent and a soft brush.
10. Wire routing should be preplanned with no wiring routed over the strain gauge active grids.
11. Check the resistance at the end of the leadwires to verify that the total resistance is appropriate for the gauge and it’s lead wire system.
12. Check the gauge/wiring installation to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be greater than 10 Gig-ohms.

Moisture-proofing Procedure

The procedure for moisture-proofing gauges for laboratory testing scenarios will necessarily vary depending on the size, design, and operational environment of the test article as well as the type of gauge. Some moisture-proofing schemes are unavoidably quite complicated. The steps below are provided only as a “good practice” guide for one type of moisture barrier. All gauges are to be coated in certain areas with a moisture-barrier coating and the coating is to be applied immediately following in Step 12 of the previous section. The moisture-barrier is to be M-Coat A. Generally, it is to be applied as follows:

1. Flush the installed gauge with an appropriate degreasing solution. Follow this with a flushing of 200 proof alcohol.
2. The gauged surface is to be at a temperature between 74°F and 80°F during the coating applications.
3. Coat all gauge solder tabs and all uninsulated wiring with an initial coat of M-Coat A. The coating thickness should be 0.003” to 0.005” thick.
4. Allow this coating to air dry for a minimum of 20 minutes at room temperature.
5. Apply a second coating over the first. This coating should overlap all edges of the first coating.
6. Allow this coating to air dry for a minimum of one hour at room temperature prior to testing.

INSTALLATION TYPE 2 – Carbon or Glass/Epoxy Composites for -450°F To 250°F Testing

NOTES: The following materials and procedures are applicable for gauging epoxy-based composites for test article structural analysis or materials properties testing at temperatures from -450°F to 250°F. Included in this installation type are composites that may or may not have a polymer added to the epoxy. **It should be noted that there have been instances, though highly unlikely, in which bonded strain gauges have been sheared sufficiently to damage the gauge during thermal cycling to cryogenic temperatures of -400°F or colder. If the composite substrate is considered capable of generating such shearing action, then, a thin Kapton film should be installed as a base material prior to installing the strain gauge. This Kapton film (obtainable from a strain gauge manufacturer) can be installed using procedures applicable for cryogenic strain gauge installations.**

Gauging Materials (all materials that are an integral part of the strain-gauged composite

1. Gauge type: to be designated by test engineer, typically SK or WK series (Vishay Micro-Measurements) and for testing from room temperature to 250°F only, CEA series can be used (Vishay Micro-Measurements)
2. Adhesive type for applying gauges: M-Bond 610; see "**Installation of the Gauges**" note following the section "**Surface Preparation for Gauging**"; adhesive type for PRT's when required: EA-934 (Hysol)
3. Wiring Terminals type: CPF series (Vishay Micro-Measurements); size of gauge determines which size to use
4. Gauge-to-Terminal Jumper Wire, when required: single strand, AWG#40, silver-clad copper
5. Platinum Resistance Thermometers (PRT's) when required, type: EL-700T (Hy-Cal)
6. Leadwires, type and length: specified by test engineer; typically wiring is a 3-conductor flat ribbon, AWG #30, Teflon insulated
7. Solder type: 361A (Vishay Micro-Measurements)
8. Protective Coating over exposed solder joints and uninsulated wiring, typically, type: N-1 (Texas Measurements)

   Note: For long-term testing that will include thermal cycling to 250°F, RTV-159 (General Electric) is recommended. This RTV does not, however, provide the degree of moisture protection that the N-1 provides. The RTV-159 must be applied at the minimum height sufficient to cover exposed solder joints and wiring.
9. Lead wire hold-down, typically, aluminum tape strips, type: FA-2 (Vishay Micro-Measurements), or RTV-159 (General Electric).

   NOTE: Depending on the testing conditions, both may be used in an alternating manner along the lead wire route.

Surface Preparation for Gauging Including Surface Basecoating When Required

1. Degrease and clean the surface(s) to be gauged. This is typically accomplished with a vapor degreasing solvent rinse, types: ENSOLV (Envirotech) or Hypersolve (Ecolink).
2. Perform a visual examination (microscopic when possible) of the areas to be gauged and the test article in general, looking for flaws in surface, i.e., delamination, cracks, broken fibers, voids, sharp edges, etc.
3. Rinse the areas to be gauged with ethyl alcohol 200 proof.

4. Mask appropriate areas of the test article for micro-sandblasting operation.
5. Micro-sandblast areas to be gauged using 50 micron Al_2O_3 abrasive powder. When micro-sandblasting is not possible, use hand-sanding with 220 grit silicon-carbide abrasive paper.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the solvent degreasing and alcohol rinse operations.

Note: Epoxy-based composites can be porous or quite rough or both. When either is encountered, a surface basecoat should be applied in the areas to be gauged. Following are steps for surface basecoating prior to the actual gauging process.

8. Apply a liberal coat of Hysol EA934 adhesive to the sandblasted areas with a thickness sufficient enough to cover the peaks of the rough surface.
9. Cure the test article for 1 hour at 250°F. An acceptable alternative cure would be to cure the test article for 4 hours at 200°F. If there is no allowance for heating the test article as above, then, a different basecoat is recommended. M-Bond GA-2 can be used for -450°F to 200°F testing and to 250°F for short-term elevated temperature test scenarios. It can be applied as in Step 8 and cured overnight at a minimum temperature of 80°F.
10. Once the basecoat is cured, it should be abraded until a uniformly textured surface is obtained. This hand-sanding operation should be performed using 220 grit silicon-carbide paper removing only an amount of the Hysol EA934 (or GA-2) sufficient to expose the fiber surface peaks.
11. Clean the basecoated areas once more with the alcohol.

<u>Installation of the Gauges</u>

Note: The following strain gauge installation procedure is applicable for long-term testing of the composite test article at temperatures ranging from -450°F to 250°F.

1. Areas to be gauged should be cleaned once again with 200 proof alcohol.
2. Make alignment marks in the appropriate location on test article surface (or along the edges of the EA-934 basecoat if used) such that they will align just outside the alignment marks around the four sides of the strain gauge backing.
3. The gauge to be installed is placed on a clean glass plate, underside down. A piece of Teflon tape (CHR, Inc. type C) is then applied to the topside of the gauge.
4. Next, transfer the gauge to the test article and position it in the area where the gauge alignment marks have been made.
5. Then lift the gauge up at one end using the Teflon tape. Fold the gauge back such that the underside of the gauge is up.
6. Brush a layer of M-Bond 610 adhesive onto the underside of the gauge and onto the surface to be gauged. Again, this surface may actually be a basecoat of EA-934 (or the M-Bond GA-2).
7. Allow the adhesive to air dry for at least ten minutes at room temperature.
8. Lift the gauge again using the tape and place it back in position on the composite surface. It will, of course, be mated with the M-Bond 610 already on the surface.

9. Now, apply a uniform pressure of 30psi to 40psi to the gauge installation. A parallel bar clamp arrangement with a silicone rubber pad is typically used for maintaining pressure on the installation during the adhesive curing process.
10. Place the test article in a temperature chamber and raise the temperature to 250°F .
11. Cure the installation at 250°F for two hours.
12. Following the adhesive cure cycle, remove the pressure applicator and the Teflon tape. Inspect the installation for voids, uneven glue-line, and gauge alignment.
13. Post cure the installation at 250°F for two hours.
    Note: When elevated temperature curing <u>is not allowed</u>, GA-2 adhesive can be used for applying the gages just as described in **<u>APPLICATION CLASS III</u>, INSTALLATION TYPE 1,** including the adhesive curing procedures**.**

<u>Wiring the Gauge</u>

Note: Because of the considerable variation in gauge construction and size it is not possible to itemize and detail a standard wiring procedure for all Langley gauge installations in this "installation type." Nonetheless, certain steps can be detailed while others must be generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gauge (to the nearest hundredth of an ohm) at the gauge wiring ribbons or for SK series, the gauge's solder tabs.
2. Using a hard rubber eraser, remove the oxidation from the gauge terminals.
3. Install and solder the gauge jumpers (when used) between the gauge tabs and the wiring terminals. All soldering for these test articles should be performed using the NASA soldering handbook titled, "NHB 5300.4(3A-1)" as a guide.
4. Remove the flux residue from the solder joints (and the gauge jumper wires when used) using a degreasing solvent and a soft brush.
5. Record the resistance of each gauge again at the wiring terminals. Compare this to the resistances recorded in Step 1. This will confirm the integrity of the gage wiring ribbon (or gauge jumpers) at the wiring terminals.
6. Strip both ends of the strain gauge leadwires and inspect for nicks in the strands. Tin the wires.
7. Position the leadwires at the end of the gauge and provide a mechanical strain relief in the leadwires near the gauge.
8. Secure the leadwires to the surface of the test article and solder the wires to the gauge solder tabs.
9. Remove the flux residue from the soldered areas using a degreasing solvent and a soft brush.
10. Wire routing should be preplanned with no wiring routed over the strain gauge active grids.
11. Check the resistance at the end of the leadwires to verify that the total resistance is appropriate for the gauge and it's lead wire system.
12. Check the gauge/wiring installation to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be greater than 10 Gig-ohms.

Moisture-proofing Procedure

The procedure for moisture-proofing gauges for laboratory testing scenarios will necessarily vary depending on the size, design, and operational environment of the test article as well as the type of gauge. Some moisture-proofing schemes are unavoidably quite complicated. The steps below are provided only as a “good practice” guide for one type of moisture barrier. All gauges are to be coated in certain areas with a moisture-barrier coating and the coating is to be applied immediately following in Step 12 of the previous section. The moisture-barrier is to be N-1 (Texas Measurements). Generally, it is to be applied as follows:

1. Flush the test article with an appropriate degreasing solution. Follow this with a flushing of 200 proof alcohol.
2. The test article is to be at a temperature between 74°F and 80°F during the coating applications.
3. Coat all gauge solder dots, gauge jumpers, solder joints, and all uninsulated wiring with an initial coat of N-1. The coating thickness should be 0.005” to 0.007” thick.
4. Allow this coating to air dry for a minimum of 20 minutes at room temperature.
5. Apply a second coating over the first. This coating should overlap all edges of the first coating.
6. Allow this coating to air dry for a minimum of one hour at room temperature prior to commencing testing. No moisture-proofing is to be applied over the active grid areas of the gauges.

INSTALLATION TYPE 3 – Carbon or Glass/Epoxy Composites for -320°F To 500°F Testing

NOTE: The following materials and procedures are applicable for gauging epoxy-based composites for test article structural analysis or materials properties testing at temperatures from -320°F to 500°F. The materials and gauging description should be applicable down to liquid Helium temperature also, but this has not been verified at NASA Langley. Included in this installation type are composites that may or may not have a polymer added to the epoxy.

Gauging Materials (all materials that are an integral part of the strain-gauged composite

1. Gauge type: to be designated by test engineer, typically SK or WK series (Vishay Micro-Measurements
2. Adhesive type for applying gauges: M-Bond 450
3. Wiring Terminals type: CPF series (Vishay Micro-Measurements); size of gauge determines which size to use
4. Gauge-to-Terminal Jumper Wire, when required: single strand, AWG#40, silver-clad copper
5. Leadwires, type and length: specified by test engineer; typically wiring is a 3-conductor flat ribbon, AWG #30, Teflon insulated
6. Solder type: 570-28R (Vishay Micro-Measurements)
7. Moisture-proofing (if needed), type: RTV-159 (General Electric)
   Note: This coating does not provide for optimum moisture protection, but it will tolerate temperatures from -450°F to 500°F
8. Lead wire hold-down, Omegabond 200 (Omega) or RTV-159 (General Electric).
   NOTE: Depending on the testing conditions, both may be used in an alternating manner along

the lead wire route. When possible, all areas receiving lead wire hold-down should be sanded and cleaned prior to application of the lead wire hold-down material.

Surface Preparation for Gauging Including Surface Basecoating When Required

1. Degrease and clean the surface(s) to be gauged. This is typically accomplished with a vapor degreasing solvent rinse, types: ENSOLV (Envirotech) or Hypersolve (Ecolink).
2. Perform a visual examination (microscopic when possible) of the areas to be gauged and the test article in general, looking for flaws in surface, i.e., delamination, cracks, broken fibers, voids, sharp edges, etc.
3. Rinse the areas to be gauged with ethyl alcohol 200 proof.
4. Mask appropriate areas of the test article for micro-sandblasting operation.
5. Micro-sandblast areas to be gauged using 50 micron Al_2O_3 abrasive powder. When micro-sandblasting is not possible, use hand-sanding with 220 grit silicon-carbide abrasive paper.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the solvent degreasing and alcohol rinse operations.

Note: Epoxy-based composites can be porous or quite rough or both. When either is encountered, a surface basecoat should be applied in the areas to be gauged. Following are steps for surface basecoating prior to the actual gauging process. This process is completed much like that used for installing the gauge.

8. Apply M-Bond 450 adhesive to the sandblasted areas. This adhesive may not provide sufficient thickness to cover the peaks of the rough surface but should be adequate to provide a surface suitable for applying the strain gauge.
9. Air dry the adhesive for 20 minutes at room temperature.
10. Place a thin Teflon sheet over the adhesive, add a silicone rubber pad and an appropriate clamping device as would be done during a gauge installation. The clamping pressure should be 30psi to 40psi.
11. Place the test article in a temperature and raise the temperature to 225°F. Hold at that temperature for 30 minutes.
12. Without returning to room temperature, raise the temperature to 350°F and hold there for 1 hour.
13. Following this, cool the test article to room temperature, and remove the clamp, pad, and Teflon.
14. Once the basecoat is cured, it should be abraded until a uniformly textured surface is obtained. This hand-sanding operation should be performed using 220 grit silicon-carbide paper removing only an amount of the M-Bond 450 sufficient to generate a textured finish suitable for installing the strain gauge.
15. Clean the basecoated areas once more with the alcohol.

Installation of the Gauges

Note: The following strain gauge installation procedure is applicable for long-term testing of the composite test article at temperatures ranging from -320°F (should be useful down to -450°F) to 500°F.

1. Areas to be gauged should be cleaned once again with 200 proof alcohol.
2. Make alignment marks in the appropriate location on test article surface (or along the edges of the M-Bond 450 adhesive basecoat if used) such that they will align just outside the alignment marks around the four sides of the strain gauge backing.
3. The gauge to be installed is placed on a clean glass plate, underside down. A piece of Teflon tape (CHR, Inc. type C) is then applied to the topside of the gauge.
4. Next, transfer the gauge to the test article and position it in the area where the gauge alignment marks have been made.
5. Then lift the gauge up at one end using the Teflon tape. Fold the gauge back such that the underside of the gauge is up.
6. Brush a layer of M-Bond 450 adhesive onto the underside of the gauge and onto the surface to be gauged. Again, this surface may actually be a basecoat of M-Bond 450.
7. Allow the adhesive to air dry for at least twenty minutes at room temperature.
8. Lift the gauge again using the tape and place it back in position on the composite surface. It will, of course, be mated with the M-Bond 450 already on the surface.
9. Now, apply a uniform pressure of 60psi to the gauge installation. A parallel bar clamp arrangement with a silicone rubber pad is typically used for maintaining pressure on the installation during the adhesive curing process.
10. Place the test article in a temperature chamber and raise the temperature to 225°F, hold at that temperature for 30 minutes and, then raise the temperature to 350°F.
11. Cure the installation at 350°F for one hour.
12. Following the adhesive cure cycle, remove the pressure applicator and the Teflon tape. Inspect the installation for voids, uneven glue-line, and gauge alignment.
13. If allowed, the installation should be post cured at the maximum test temperature for 30 minutes.

Wiring the Gauge

Note: Because of the considerable variation in gauge construction and size it is not possible to itemize and detail a standard wiring procedure for all Langley gauge installations in this "installation type." Nonetheless, certain steps can be detailed while others must be generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gauge (to the nearest hundredth of an ohm) at the gauge wiring ribbons or for SK series, the gauge's solder tabs.
2. Using a hard rubber eraser, remove the oxidation from the gauge terminals.
3. Install and solder the gauge jumpers (when used) between the gauge tabs and the wiring terminals. All soldering for these test articles should be performed using the NASA soldering handbook titled, "NHB 5300.4(3A-1)" as a guide.
4. Remove the flux residue from the solder joints (and the gauge jumper wires when used) using a degreasing solvent and a soft brush.
5. Record the resistance of each gauge again at the wiring terminals. Compare this to the resistances recorded in Step 1. This will confirm the integrity of the gage wiring ribbon (or gauge jumpers) at the wiring terminals.

6. Strip both ends of the strain gauge leadwires and inspect for nicks in the strands. Tin the wires.
7. Position the leadwires at the end of the gauge and provide a mechanical strain relief in the leadwires near the gauge.
8. Secure the leadwires to the surface of the test article and solder the wires to the gauge solder tabs.
9. Remove the flux residue from the soldered areas using a degreasing solvent and a soft brush.
10. Wire routing should be preplanned with no wiring routed over the strain gauge active grids.
11. Check the resistance at the end of the leadwires to verify that the total resistance is appropriate for the gauge and it's lead wire system.
12. Check the gauge/wiring installation to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be greater than 10 Gig-ohms.

Moisture-proofing Procedure

The procedure for moisture-proofing strain gauges on this type of test article will necessarily vary depending on the size, design, and operational environment of the test article and, in fact, a moisture-barrier may not be necessary. The steps below are provided only as a "good practice" guide. The moisture-barrier is to be RTV-3140. Generally, it is to be applied as follows:

1. Flush the strain-gauged area with an appropriate degreasing solution. Follow this with a flushing of 200 proof alcohol.
2. The test article is to be at a temperature between 74°F and 80°F during the coating applications.
3. Coat all gauge solder dots, gauge jumpers, solder joints, and all uninsulated wiring with an initial application of RTV-3140. The coating thickness should be 0.020" to 0.030".
4. Allow this coating to airdry overnight at room temperature.
5. A second coat of the RTV-3140 can be added following the curing of the first application. The second coating should be applied directly to the first coating and it should extend just beyond the boundaries of the first coat. The total thickness for the two coats should not exceed 0.060".

INSTALLATION TYPE 4 – Silicon-Carbide (SiC) Surface Composites for Room Temperature Testing

NOTE: Composites often referred to as Carbon/Carbon (C/C) composites and Carbon/Silicon-Carbide (C/SiC) composites typically contain a silicon-carbide surface and that surface is most often coated with some type of high-temperature sealing coat. The installation procedure described here is applicable for C/SiC surface composites with or without the sealing coat. To date, no sealing coat has proven to be a deterrent to the bonding application as presented below.

Gauging Materials (all materials that are an integral part of the strain-gauged composite

1. Gauge type: to be designated by test engineer, typically CEA series (Vishay Micro-Measurements)
2. Adhesive type: M-Bond GA-2 or M-Bond 200 (Vishay Micro-Measurements) – See "**Installation of the Gauges**" note following the section "**Surface Preparation for Gauging**"

3. Strain Gauge Leadwires, type and length: specified by test engineer; typically wiring is a 3-conductor flat ribbon, size AWG#30, stranded, tinned copper with a vinyl insulation over each conductor
4. Solder type: 361-A (Vishay Micro-Measurements)
5. Protective Gauge Coating when required, type: M-Coat A (Vishay Micro-Measurements)
6. Lead wire hold-down, typically, aluminum tape strips, type: FA-2 (Vishay Micro-Measurements), or silicone rubber, type: 3145-RTV (Vishay Micro-Measurements)
   NOTE: Depending on the testing conditions, both may be used in an alternating manner along the lead wire route. When possible, sanding and cleaning of the areas to receive the lead wire hold-down should be conducted.

Surface Preparation for Gauging Including Surface Basecoating When Required

1. Degrease and clean the surface(s) to be gauged. This is typically accomplished with a vapor degreasing solvent rinse, types: ENSOLV (Envirotech) or Hypersolve (Ecolink).
2. Perform a visual examination (microscopic when possible) of the areas to be gauged and the test article in general, looking for flaws in surface. .
3. Rinse the areas to be gauged with ethyl alcohol 200 proof.
4. Mask appropriate areas of the test article for micro-sandblasting operation.
5. Micro-sandblast areas to be gauged using 50 micron Al_2O_3 abrasive powder. When micro-sandblasting is not possible, use hand-sanding with 220 grit silicon-carbide abrasive paper.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the solvent degreasing and alcohol rinse operations.

Note: Silicon-Carbide surfaces on composites can be quite rough. When this is encountered, a surface basecoat should be applied in the areas to be gauged. Following are steps for surface basecoating prior to the actual gauging process.

8. Apply a liberal coat of M-Bond GA-2 adhesive to the sandblasted areas with a thickness sufficient enough to cover the peaks of the rough surface.
9. On flat surfaces this M-Bond GA-2 adhesive basecoat can be left to dry as is. On surfaces where sag or runoff is a concern, place a Teflon film pad over the basecoat, install a vacuum applicator pad over the Teflon, and apply vacuum to the applicator pad.
10. Cure the test article for 4 hours at a minimum temperature of 100°F. An acceptable alternative cure would be to cure the test article for 2 hours at 125°F. If there is no allowance for heating the test article as above, then, the basecoat must be cured overnight at a minimum temperature of 80°F.
11. Once the basecoat is cured, it should be hand-sanded until a uniformly textured surface is obtained. This abrading operation should be performed using 220 grit silicon-carbide paper removing only an amount of the GA-2 sufficient to expose the C/SiC surface peaks.
12. Clean the basecoated areas once more with the alcohol.

Installation of the Gauges

Note: The following strain gauge installation procedure is applicable for long-term testing of the test article being instrumented. If it can be determined with certainty that the test article being gauged will be maintained in a temperature and humidity-controlled environment, then, M-Bond 200 adhesive can be substituted for the M-Bond GA-2 adhesive approach. For porous or rough composite surfaces, the basecoating operation would still be needed. The gauging procedure to be followed when using the M-Bond 200 adhesive is offered by Vishay Micro-Measurements, Inc. in their product catalog under the section titled, "TECH TIPS." The appropriate Tech Tip is titled, "Instruction Bulletin B-127-13." The following steps are applicable for gauging this class of composites using M-Bond GA-2 adhesive.

1. Areas to be gauged should be cleaned once again with 200 proof alcohol.
2. Make alignment marks in the appropriate location on test article surface (or along the edges of the GA-2 basecoat if used) such that they will align just outside the alignment marks around the four sides of the strain gauge backing.
3. The gauge to be installed is placed on a clean glass plate, underside down. A piece of Teflon tape (CHR, Inc. type C) is then applied to the topside of the gauge.
4. Next, transfer the gauge to the test article and position it in the area where the gauge alignment marks have been made.
5. Then lift the gauge up at one end using the Teflon tape. Fold the gauge back such that the underside of the gauge is up.
6. Brush a layer of M-Bond GA-2 adhesive onto the underside of the gauge and onto the surface to be gauged. Again, this surface may actually be a basecoat of the M-Bond GA-2.
7. When the appropriate viscosity of the M-Bond GA-2 is realized, lift the gauge again using the tape and place it back in position on the composite surface. It will, of course, be mated with the M-Bond GA-2 already on the surface.
   Note: If the viscosity of the M-Bond GA-2 is too thin or too viscous, glue-line voids or non-uniform glue-line thickness could occur. A rule-of-thumb for this type of application is that the viscosity is ideal at about one-half of the working pot life of the mixed adhesive.
8. Now, apply a uniform pressure of 10psi to 15psi to the gauge installation. A parallel bar clamp arrangement with a silicone rubber pad or a vacuum pad device can usually be used for maintaining pressure on the installation during the adhesive curing process.
9. Cure the installation at 100°F for four hours or at 125°F for two hours. If heating of the test article is not allowed, then, the installation must be cured overnight at a minimum temperature of 80°F.
10. Following the adhesive cure cycle, remove the pressure applicator and the Teflon tape. Inspect the installation for voids, uneven glue-line, and gauge alignment. Because this procedure applies to room temperature testing only, no post curing of the installation is necessary.

Wiring the Gauge

Note: Because of the considerable variation in gauge construction and size it is not possible to itemize and detail a standard wiring procedure for all Langley gauge installations in this "installation type." Nonetheless, certain steps can be detailed while others must be generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gauge (to the nearest hundredth of an ohm) at the gauge's solder tabs.
2. Using a hard rubber eraser, remove the oxidation from the gauge terminals.
3. Apply solder the gauge terminals. All soldering for this type of installation should be performed using the NASA soldering handbook titled, "NHB 5300.4(3A-1)" as a guide.
4. Remove the flux residue from the soldered areas using a degreasing solvent and a soft brush.
5. Record the resistance of each gauge again at the solder tabs. Compare this to the resistances recorded in Step 1. This will confirm the integrity of the solder at the gauge tabs.
6. Strip both ends of the strain gauge leadwires and inspect for nicks in the strands. Tin the wires.
7. Position the leadwires at the end of the gauge and provide a mechanical strain relief in the leadwires near the gauge.
8. Secure the leadwires to the surface of the test article and solder the wires to the gauge solder tabs.
9. Remove the flux residue from the soldered areas using a degreasing solvent and a soft brush.
10. Wire routing should be preplanned with no wiring routed over the strain gauge active grids.
11. Check the resistance at the end of the leadwires to verify that the total resistance is appropriate for the gauge and it's lead wire system.
12. Check the gauge/wiring installation to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be greater than 10 Gig-ohms.

Moisture-proofing Procedure

The procedure for moisture-proofing gauges for laboratory testing scenarios will necessarily vary depending on the size, design, and operational environment of the test article as well as the type of gauge. Some moisture-proofing schemes are unavoidably quite complicated. The steps below are provided only as a "good practice" guide for one type of moisture barrier. All gauges are to be coated in certain areas with a moisture-barrier coating and the coating is to be applied immediately following in Step 12 of the previous section. The moisture-barrier is to be M-Coat A. Generally, it is to be applied as follows:

1. Flush the installed gauge with an appropriate degreasing solution. Follow this with a flushing of 200 proof alcohol.
2. The gauged surface is to be at a temperature between 74°F and 80°F during the coating applications.
3. Coat all gauge solder tabs and all uninsulated wiring with an initial coat of M-Coat A. The coating thickness should be 0.003" to 0.005" thick.
4. Allow this coating to air dry for a minimum of 20 minutes at room temperature.
5. Apply a second coating over the first. This coating should overlap all edges of the first coating.
6. Allow this coating to air dry for a minimum of one hour at room temperature prior to testing.

INSTALLATION TYPE 5 – Metal Matrix Composites for Room Temperature Testing

NOTE: To date, all metal matrix composites requiring strain gages for testing at NASA Langley have had titanium or aluminum as the matrix material. No custom gage installation procedure is required for strain-gauging these materials for room temperature testing other than recognizing that they oxidize rapidly, and therefore, the application steps for installation of the gauge should begin immediately following the surface preparation steps. The Vishay Micro-Measurements, Inc. instruction bulletin B-127-9 titled "Strain Gage Installation with M-Bond 200 Adhesive" works well for installing gauges on metal matrix composites when short-term testing is required. For long-term testing, the gauging procedure presented in this document under **APPLICATION CLASS III, INSTALLATION TYPE 1,** can be used.

INSTALLATION TYPE 6 – Metal Matrix Composites for -450°F to 400°F Testing

Gauging Materials (all materials that are an integral part of the strain-gauged composite

1. Gauge type: to be designated by test engineer, typically SK or WK series (Vishay Micro-Measurements
2. Adhesive type for applying gauges: M-Bond 450
3. Wiring Terminals type: CPF series (Vishay Micro-Measurements); size of gauge determines which size to use
4. Gauge-to-Terminal Jumper Wire, when required: single strand, AWG#40, silver-clad copper
5. Leadwires, type and length: specified by test engineer; typically wiring is a 3-conductor flat ribbon, AWG #30, Teflon insulated
6. Solder type: 570-28R (Vishay Micro-Measurements)
7. Moisture-proofing (if needed), type: RTV-159 (General Electric)
   Note: This coating does not provide for optimum moisture protection, but it will tolerate temperatures from -450°F to 500°F. If the maximum testing temperature will not exceed 200°F, it is recommended that a custom rubber coating available from Texas Measurements, Inc., type: N-1, be used.
8. Lead wire hold-down, aluminum tape strips, type: FA-2 (Vishay Micro-Measurements) or RTV-159 (General Electric).
   NOTE: Depending on the testing conditions, both may be used in an alternating manner along the lead wire route. When possible, all areas receiving lead wire hold-down should be sanded and cleaned prior to application of the lead wire hold-down material.

Surface Preparation for Gauging

1. Degrease and clean the surface(s) to be gauged. This is typically accomplished with a vapor degreasing solvent rinse, types: ENSOLV (Envirotech) or Hypersolve (Ecolink).
2. Perform a visual examination (microscopic when possible) of the areas to be gauged and the test article in general, looking for flaws in surface.
3. Rinse the areas to be gauged with ethyl alcohol 200 proof.
4. Mask appropriate areas of the test article for micro-sandblasting operation.
5. Micro-sandblast areas to be gauged using 50 micron Al_2O_3 abrasive powder. When micro-sandblasting is not possible, use hand-sanding with 280 or 320 grit silicon-carbide abrasive paper.

6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the solvent degreasing and alcohol rinse operations. The gauge installation steps must begin immediately following this step.
8. When more than one gauging adhesive curing cycle is required, the previous steps 3 through 7 must be repeated for each curing cycle.

Installation of the Gauges

1. Areas to be gauged should be cleaned once again with 200 proof alcohol.
2. Make alignment marks in the appropriate location on test article surface (or along the edges of the M-Bond 450 adhesive basecoat if used) such that they will align just outside the alignment marks around the four sides of the strain gauge backing.
3. The gauge to be installed is placed on a clean glass plate, underside down. A piece of Teflon tape (CHR, Inc. type C) is then applied to the topside of the gauge.
   NOTE: This step should be performed prior to the surface preparation steps.
4. Next, transfer the gauge to the test article and position it in the area where the gauge alignment marks have been made.
5. Then lift the gauge up at one end using the Teflon tape. Fold the gauge back such that the underside of the gauge is up.
6. Brush a layer of M-Bond 450 adhesive onto the underside of the gauge and onto the surface to be gauged.
7. Allow the adhesive to air dry for at least twenty minutes at room temperature.
8. Lift the gauge again using the tape and place it back in position on the test article surface. It will, of course, be mated with the M-Bond 450 already on the surface.
9. Now, apply a uniform pressure of 60psi to the gauge installation. A parallel bar clamp arrangement with a silicone rubber pad is typically used for maintaining pressure on the installation during the adhesive curing process.
10. Place the test article in a temperature chamber and raise the temperature to 225°F, hold at that temperature for 30 minutes and, then raise the temperature to 350°F.
11. Cure the installation at 350°F for one hour.
12. Following the adhesive cure cycle, remove the pressure applicator and the Teflon tape. Inspect the installation for voids, uneven glue-line, and gauge alignment.
13. If allowed, the installation should be post cured at the maximum test temperature for 30 minutes.

Wiring the Gauge

Note: Because of the considerable variation in gauge construction and size it is not possible to itemize and detail a standard wiring procedure for all Langley gauge installations in this “installation type.” Nonetheless, certain steps can be detailed while others must be generalized. The steps below are provided only as a “good practice” guide.

1. On a worksheet, record the resistance of each gauge (to the nearest hundredth of an ohm) at the

gauge wiring ribbons or for SK series, the gauge's solder tabs.

2. Using a hard rubber eraser, remove the oxidation from the gauge terminals.
3. Install and solder the gauge jumpers (when used) between the gauge tabs and the wiring terminals. All soldering for these test articles should be performed using the NASA soldering handbook titled, "NHB 5300.4(3A-1)" as a guide.
4. Remove the flux residue from the solder joints (and the gauge jumper wires when used) using a degreasing solvent and a soft brush.
5. Record the resistance of each gauge again at the wiring terminals. Compare this to the resistances recorded in Step 1. This will confirm the integrity of the gage wiring ribbon (or gauge jumpers) at the wiring terminals.
6. Strip both ends of the strain gauge leadwires and inspect for nicks in the strands. Tin the wires.
7. Position the leadwires at the end of the gauge and provide a mechanical strain relief in the leadwires near the gauge.
8. Secure the leadwires to the surface of the test article and solder the wires to the gauge solder tabs.
9. Remove the flux residue from the soldered areas using a degreasing solvent and a soft brush.
10. Wire routing should be preplanned with no wiring routed over the strain gauge active grids.
11. Check the resistance at the end of the leadwires to verify that the total resistance is appropriate for the gauge and it's lead wire system.
12. Check the gauge/wiring installation to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be greater than 10 Gig-ohms.

<u>Moisture-proofing Procedure</u>

The procedure for moisture-proofing strain gauges on this type of test article will necessarily vary depending on the size, design, and operational environment of the test article and, in fact, a moisture-barrier may not be necessary. The steps below are provided only as a "good practice" guide. The moisture-barrier is to be RTV-3140. Generally, it is to be applied as follows:

1. Flush the strain-gauged area with an appropriate degreasing solution. Follow this with a flushing of 200 proof alcohol.
2. The test article is to be at a temperature between 74°F and 80°F during the coating applications.
3. Coat all gauge solder dots, gauge jumpers, solder joints, and all uninsulated wiring with an initial application of RTV-3140. The coating thickness should be 0.020" to 0.030".
4. Allow this coating to airdry overnight at room temperature.
5. A second coat of the RTV-3140 can be added following the curing of the first application. The second coating should be applied directly to the first coating and it should extend just beyond the boundaries of the first coat. The total thickness for the two coats should not exceed 0.060".

INSTALLATION TYPE 7 – Metal Matrix Composites for 400°F to 700°F Testing

NOTE: For testing scenarios where temperatures above 400°F but not exceeding 700°F, consideration must be given to the test parameters. Applicable gauging materials and application procedure will be driven by several factors including the actual test temperature, the duration of the test(s) and/or number of thermal cycles, strain levels, data accuracy requirements, static or dynamic testing, etc. The gauging procedure must be custom suited to the test scenario. Because of this, no particular gauge application procedure is detailed here. However, the gauging procedure described in **APPLICATION CLASS IV, INSTALLATION TYPE 3** will probably serve as a useful guide.

APPLICATION CLASS IV – STRAIN GAUGE INSTALLATION PROCEDURES FOR NON-TYPCIAL OR UNIQUE MATERIALS AND TEST SCENARIOS NOT COVERED UNDER APPLICATION CLASSES I THROUGH III

NOTE: This application class details gauging procedures for only three non-typical or unique strain gauge application requirements. Although there are only three installation types described, these should be useful as guides for certain other unusual gauging scenarios.

INSTALLATION TYPE 1 – Aluminum/Lithium for Testing from Room Temperature to -320°F

NOTE: The following materials and procedures are applicable for aluminum/lithium test articles that are to be tested at temperatures ranging from room temperature down to -320°F. The materials and procedures listed here are specifically for aluminum/lithium test articles that cannot be subjected to elevated temperatures during the gauging application process. The following strain gauge installation procedure is useful for long-term as well as short-term testing of this material. Laboratory testing has determined that methyl-cyanoacrylate adhesives do not provide sufficient bonding strength for strain gauges on aluminum/lithium. Also, laboratory testing has verified that Vishay Micro-Measurements, Inc. adhesive type: M-BOND AE-10 bonds well enough to measure strains up to 1.5% on this material. It is imperative that the application of the gauging adhesive to the aluminum/lithium surface be undertaken immediately upon completion of the surface preparation procedure.

Gauging Materials (all materials that are an integral part of the strain-gauged test article)

1. Gauge type: to be designated by test engineer, typically WK or SK series (Vishay Micro-Measurements) Note: If testing were to be conducted at room temperature only, then, CEA series gages could be used.
2. Adhesive type: M-Bond AE-10 (Vishay Micro-Measurements)
3. Wiring terminals for strain gauges, type: CPF (Vishay Micro-Measurements)
4. Gauge-to-Jumper Wire: AWG#38 silver-clad copper
5. Leadwires for strain gauges, type: 3-conductor, twisted, AWG32, stranded (7-40), silver-clad copper, Teflon-insulated (Tensolite Co.)
6. Solder for all strain gauges, type: M-Line 361A (Vishay Micro-Measurements)
7. Lead wire hold-down, aluminum tape strips, type: FA-2 (Vishay Micro-Measurements) or RTV-159 (General Electric).
   NOTE: Depending on the testing conditions, both may be used in an alternating manner along the lead wire route. When possible, all areas receiving lead wire hold-down should be sanded and cleaned prior to application of the lead wire hold-down material.
8. Moisture-barrier (when required) type: N-1 (Texas Measurements)

Surface Preparation for Gauging

1. Degrease the surface area to be gauged with degreaser type: CSM-1A (Vishay Micro-Measurements) by saturating a gauze sponge or lab-type tissue and wiping. Repeat until the sponge/tissue is clean.
2. Micro-sandblast the surface area using 80-grit Al_2O_3 abrasive powder.
3. Wipe the sandblasted area with a gauze sponge or tissue saturated with M-Prep Conditioner A (Vishay Micro-Measurements).
4. Wipe the area clean and dry using a dry gauze sponge or lab-type tissue. Wipe in one direction only and then discard the sponge/tissue for a new one.
5. Burnish any needed alignment marks on the surface.
6. Flood the surface with M-Prep Conditioner A and thoroughly scrub using a cotton-tipped applicator. Wipe clean and dry using a dry gauze sponge/tissue. Wipe in one direction only and then discard the sponge for a new one.
7. Flood the surface with M-Prep Neutralizer 5A (Vishay Micro-Measurements) and thoroughly scrub using a cotton-tipped applicator. Wipe clean and dry using a dry gauze sponge/tissue. Wipe in one direction only and then discard the sponge for a new one.
8. Position and bond the strain gage within **10 minutes** to minimize any surface degradation due to oxidation.

Installation of the Gauges

1. The gauge to be installed is placed on a clean glass plate, underside down. A piece of Teflon tape (CHR, Inc. type C) is then applied to the topside of the gauge.
   NOTE: This step should be performed prior to the surface preparation steps.
2. Next, transfer the gauge to the test article and position it in the area where the gauge alignment marks have been made.
3. Then lift the gauge up at one end using the Teflon tape. Fold the gauge back such that the underside of the gauge is up.
4. Brush a layer of M-Bond AE-10 adhesive onto the underside of the gauge and onto the adjacent surface to be gauged.
5. When the appropriate viscosity of the M-Bond AE-10 is realized, lift the gauge again using the tape and place it back in position on the composite surface. It will, of course, be mated with the M-Bond AE-10 already on the surface.
   Note: If the viscosity of the M-Bond AE-10 is too thin or too viscous, glue-line voids or non-uniform glue-line thickness could occur. A rule-of-thumb for this type of application is that the viscosity is ideal at about one-half of the working pot life of the mixed adhesive.
6. Now, apply a uniform pressure of 10psi to 15psi to the gauge installation. A parallel bar clamp arrangement with a silicone rubber pad or a vacuum pad device can be used for maintaining pressure on the installation during the adhesive curing process.
7. Cure the installation for six hours at not more than 100°F. If heating of the test article is not allowed, then, the installation must be cured overnight at a minimum temperature of 80°F. The relatively humidity cannot exceed 40%.
8. Following the adhesive cure cycle, remove the pressure applicator and the Teflon tape. Inspect the installation for voids, uneven glue-line, and gauge alignment. Because this procedure applies to cryogenic and/or room temperature testing only, no post curing of the installation is necessary.

Wiring the Aluminum/Lithium Test Article

Note: Because of the considerable variation in gauge construction and size it is not possible to itemize and detail a standard wiring procedure for all Langley gauge installations in this "installation type." Nonetheless, certain steps can be detailed while others must be generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gauge (to the nearest hundredth of an ohm) at the gauge wiring ribbons or for SK series, the gauge's solder tabs.
2. Using a hard rubber eraser, remove the oxidation from the gauge terminals.
3. Install and solder the gauge jumpers (when used) between the gauge tabs and the wiring terminals. All soldering for these test articles should be performed using the NASA soldering handbook titled, "NHB 5300.4(3A-1)" as a guide.
4. Remove the flux residue from the solder joints (and the gauge jumper wires when used) using a degreasing solvent and a soft brush.
5. Record the resistance of each gauge again at the wiring terminals. Compare this to the resistances recorded in Step 1. This will confirm the integrity of the gage wiring ribbon (or gauge jumpers) at the wiring terminals.
6. Strip both ends of the strain gauge leadwires and inspect for nicks in the strands. Tin the wires.
7. Position the leadwires at the end of the gauge and provide a mechanical strain relief in the leadwires near the gauge.
8. Secure the leadwires to the surface of the test article and solder the wires to the gauge solder tabs.
9. Remove the flux residue from the soldered areas using a degreasing solvent and a soft brush.
10. Wire routing should be preplanned with no wiring routed over the strain gauge active grids.
11. Check the resistance at the end of the leadwires to verify that the total resistance is appropriate for the gauge and it's lead wire system.
12. Check the gauge/wiring installation to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be greater than 10 Gig-ohms.

Moisture-proofing Procedure

Moisture-proofing of gauge installations for this installation type may or may not be necessary depending on the testing environment. Some moisture-proofing schemes are unavoidably quite complicated. The moisture-barrier and its application steps below are provided only as a "good practice" guide. All gauges are to be coated in certain areas with this moisture-barrier coating and the coating is to be applied immediately following in Step 12 of the previous section. The moisture-barrier is to be N-1 (Texas Measurements). Generally, it is to be applied as follows:

1. Flush the test article with an appropriate degreasing solution. Follow this with a flushing of 200 proof alcohol.
2. The test article is to be at a temperature between 74°F and 80°F during the coating applications.
3. Coat all gauge solder dots, gauge jumpers, solder joints, and all uninsulated wiring with an initial coat of N-1. The coating thickness should be 0.005" to 0.007" thick.
4. Allow this coating to air dry for a minimum of 20 minutes at room temperature.

5. Apply a second coating over the first. This coating should overlap all edges of the first coating.
6. Allow this coating to air dry for a minimum of one hour at room temperature prior to commencing testing. No moisture-proofing is to be applied over the active grid areas of the gauges.

INSTALLATION TYPE 2 – Interior Surfaces of Cryogenic Models/Test Articles

NOTE: The following materials and gauging procedures have been successfully used on interior surfaces of maraging steel, cryogenic wind tunnel models, both in wing recesses and on interior surfaces of model wing components. The procedures described here include gauge installation and cavity filling of recessed, strain-gauged areas for aerodynamic surface forming. The operating range for this type of installation is -320°F to 175°F. This installation procedure is intended as a possible approach for situations where filling of instrumented, test article cavities for cryogenic temperature testing are encountered.

<u>Gauging Materials (all materials that are an integral part of the strain gauged test article)</u>

1. Gauge type: to be designated by test engineer, typically WK or SK series (Vishay Micro-Measurements)
2. Adhesive type: M-BOND GA-2 (Vishay Micro-Measurements) Note: M-BOND AE-10 should work equally as well.
3. Wiring terminals for strain gauges (when needed), type: CPF (Vishay Micro-Measurements)
4. Gauge-to-Jumper Wire: AWG#38 silver-clad copper
5. Leadwires for strain gauges, type: 3-conductor, twisted, AWG32, stranded (7-40), silver-clad copper, Teflon-insulated (Tensolite Co.)
6. Solder for all strain gauges, type: M-Line 361A (Vishay Micro-Measurements)
7. Lead wire hold-down, aluminum tape strips, type: FA-2 (Vishay Micro-Measurements) or RTV-159 (General Electric).
   NOTE: Depending on the testing conditions, both may be used in an alternating manner along the lead wire route. When possible, all areas receiving lead wire hold-down should be sanded and cleaned prior to application of the lead wire hold-down material.
8. Moisture-barrier (when required) type: N-1 (Texas Measurements)
9. Materials to be used to cover the gauge and fill the cavity for subsequent sanding and shaping to form aerodynamic surface are as follows: (a) Open-cell foam over gauges, type: LAST-A-FOAM (General Plastics Mfg.); Note: Insta-pak 200 works well, also; (b) Structural-type adhesive over foam, type: Hysol 9309 (Dexter Corp.); (c) Structural adhesive w/carbon sphere-filler over original structural adhesive; for this installation procedure, the adhesive is again, Hysol 9309 and the carbon spheres are type: S-100 (CarboSpheres, Inc.)

<u>Surface Preparation for Gauging</u>

1. Degrease and clean the surface(s) to be gauged. This is typically accomplished with a vapor degreasing solvent rinse, types: ENSOLV (Envirotech) or Hypersolve (Ecolink).
2. Perform a visual examination (microscopic when possible) of the areas to be gauged and the test article in general, looking for flaws in surface.
3. Rinse the areas to be gauged with ethyl alcohol 200 proof.

4. Mask appropriate areas of the test article for micro-sandblasting operation.
5. Micro-sandblast areas to be gauged using 50 micron Al_2O_3 abrasive powder. When micro-sandblasting is not possible, use hand-sanding with 280 or 320 grit silicon-carbide abrasive paper.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the solvent degreasing and alcohol rinse operations. The gauge installation steps should begin immediately following this step.

Installation of the Gauges

1. Gauges (and wiring terminals when used) should be cleaned with pure alcohol, dried, placed inverted on a clean glass plate, and ready for installation.
2. Apply a coat of M-BOND GA-2 (or AE-10) to the underside of the gauges and terminals to be installed as well as a coat to the appropriate test article surface(s).
3. Allow the items coated with the gauging adhesive to air dry at least five minutes at room temperature.
4. Place the gauges and terminals on the appropriate adhesive-coated areas of the test article and cover with a thin, pressure-sensitive Teflon tape or Teflon sheet as suitable.
5. Next, place silicone rubber pads over the Teflon in the areas where the gauges are located.
6. Apply a constant and uniform pressure of 10psi to the rubber pads using an proper clamping device.
7. Cure the installed gauges a minimum of 6 hours at a minimum temperature of 125°F. If permitted, a cure of 4 hours at 150°F is sufficient.
8. Remove the clamping device, the rubber pads, and the Teflon. Inspect the gauge installation for accuracy of alignment, glue-line voids, or foreign matter.
9. Post cure the installation for 8 hours at a minimum temperature of 125°F prior to the filling of the cavity. If permitted, a sufficient post cure can be obtained at 150°F for 6 hours.

Wiring the Model/Test Article

NOTE: Because of the considerable variation in test requirements it is not possible to itemize and detail a standard wiring procedure for all Langley test articles. Nonetheless, certain steps can be detailed and used as a "good practice" guide.

1. On a worksheet, record the resistance of each gauge at the gauge wiring terminals or gauge solder dots.
2. Remove the oxidation from the CPF terminals (when used). A hard rubber eraser works well for this.
3. Install and solder the gauge jumpers between the gauge dots and the wiring terminals. All soldering for these gauges should be performed using the NASA soldering handbook "NHB 5300.4(3A-1)" as a guide.
4. Remove the flux residue from the solder joint and the gauge jumper wires.
5. On the worksheet, record the resistance of each gauge at the wiring terminals. This will confirm the integrity of the jumper wires and the solder joints at the gauge and the terminals.
6. Carefully strip and tin all intrabridge (when required) and interbridge (when required) wiring prior to installing them at the terminals. Inspect the wiring for nicks in the strands before tinning. Note: All leadwiring that is to be potted within the model cavity must be "etched" wiring.

7. When possible, all intrabridge wires (when required) should be of equal resistance and length.
8. Wire routing should be preplanned such that no wiring will be routed over the strain gauge active grids or over the gauge jumpers (when used).
9. Once all wiring is completed, clean the test article to remove all soldering residues and any other foreign matter.
10. For single gauges, check the resistance at the end of the lead wires to verify that the total resistance is correct for this particular gauge and lead wire system.
11. If wired as bridges, check to confirm that the zeros are representative of the arbitrary differences in the resistances of the gauges that comprise the bridge circuit.
12. Check the resistance leakage to ground. This should be greater than 10 Gig-ohms.

<u>Installation of Cavity Filler Materials Over Strain Gauge Areas</u>

1. Once again, use alcohol to clean the cavity area that contains the strain gauge(s) and its ancillary wiring.
2. Apply the "LAST-A-FOAM" foam over the gauge and solder joints in the cavity. Once this two-part foam is mixed, it must be applied quickly and directly to the gauge and terminal area. Note: This material should bond to the gauge, terminals, wiring, and surrounding areas as the foaming action occurs.
3. The foam should be allowed to set un-disturbed for at least 1 hour.
4. Once the foam is set, it should be <u>carefully</u> trimmed (a scalpel usually works well) such that a coating is formed as appropriate in the cavity and approximately 1/16" in thickness above the top of the strain gauge area.
5. Next, the Hysol 9309 adhesive should be applied to the foam. This application should be approximately 1/32" thick and it should cover all of the foam.
6. Cure this adhesive coating for at least 4 hours at a minimum temperature of 75°F.
7. Finally, the Hysol 9309 with the S-100 CarboSpheres added, should be used to fill the remaining cavity area. Note: The mixing ratio for the Hysol 9309 and the CarboSpheres is 1.5 to 1.0 of carbon spheres to adhesive by weight.
8. The cavity should be filled sufficiently that sanding of the adhesive will be required for shaping and contouring the model surface.
9. The adhesive/sphere filler should be cured for at least 4 hours at a minimum temperature of 75°F.
10. Record final electrical checks to verify integrity of gauge installation and coating.

INSTALLTION TYPE 3 – Titanium/Aluminum for Testing from -320°F to 650°F

NOTE: The installation materials and procedure detailed here have only been used once at Langley and that was on a Ti-6 test plate to be subjected to multiple thermal cycles ranging from -320°F to 650°F with load applied. The approach described here worked well and is offered as a guide for other similar test scenarios where titanium/aluminum is encountered.

<u>Gauging Materials (all materials that are an integral part of the strain gauged test article)</u>

1. Gage type: WK series, (Vishay Micro-Measurements)

2. Wiring terminals, type: TL-56, (BLH) – no longer available, now available from HBM, they're offered as type:LS-2
3. Adhesive type: PLD-700, (BLH) – no longer available, HBM offers a similar adhesive as type: EP 310
4. Strain Gauge Leadwires type: 326-GJF (Vishay Micro-Measurements)
5. Solder type: 0.031" Gold alloy spheres/770°F (Clad Metals) Note: These spheres are composed of 81.5%Au; 8.5%Ag; 10-%Ge, and have a melting temperature of 770°F.
6. Moisture-barrier, type: RTV-159 (General Electric) Note: This material is also to be used for lead wire hold-down on the test article.

Surface Preparation for Gauging

1. Degrease the surface area to be gauged with degreaser type: CSM-1A (Vishay Micro-Measurements) by saturating a gauze sponge or lab-type tissue and wiping. Repeat until the sponge/tissue is clean.
2. Micro-sandblast the surface area using 50-micron Al_2O_3 abrasive powder.
3. Wipe the sandblasted area with a gauze sponge or tissue saturated with M-Prep Conditioner A (Vishay Micro-Measurements).
4. Wipe the area clean and dry using a dry gauze sponge or lab-type tissue. Wipe in one direction only and then discard the sponge/tissue for a new one.
5. Burnish any needed alignment marks on the surface.
6. Flood the surface with M-Prep Conditioner A and thoroughly scrub using a cotton-tipped applicator. Wipe clean and dry using a dry gauze sponge/tissue. Wipe in one direction only and then discard the sponge for a new one.
7. Flood the surface with M-Prep Neutralizer 5A (Vishay Micro-Measurements) and thoroughly scrub using a cotton-tipped applicator. Wipe clean and dry using a dry gauze sponge/tissue. Wipe in one direction only and then discard the sponge for a new one.
8. Position and bond the strain gage within 10 minutes to minimize any surface degradation due to oxidation.

Installation of the Gauges

1. Gauges and wiring terminals should be cleaned with pure alcohol, dried, placed inverted on a clean
   glass plate, and ready for installation. This should be done prior to performing steps 6 and 7 above.
2. With the test article also cleaned, the gauge installation and heat curing steps should begin immediately as per the manufacturer's instructions for using EP-310. Note: A polyimide-based adhesive, type: PLD-700 was originally used for this type of installation, but that adhesive is no longer available. The EP-310 should perform adequately.
3. Once the heat cure is completed and cooled, remove the clamping hardware. Inspect the gauge installation for accuracy of alignment, glue-line voids, and foreign matter.
4. When more than one cure cycle is required to complete all gage installations on a test article, the gauge areas still requiring gauges should be micro-sandblasted again and the surface preparation steps previously outlined should be repeated.

Wiring the Titanium/Aluminum Test Article

Note: Because of the considerable variation in gauge construction and size it is not possible to itemize and detail a standard wiring procedure for all Langley gauge installations in this "installation type." Nonetheless, certain steps can be detailed while others must be generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gauge (to the nearest hundredth of an ohm) at the gauge wiring ribbons.
2. Using a hard rubber eraser, remove the oxidation from the gauge ribbons and the wiring terminals.
3. Turn the ends of the wiring terminals up such that the eyelets are at 90° to the test article surface.
4. Solder the gauge ribbons to the nearest end of the wiring terminals using the solder spheres.
5. Remove the flux residue from the solder joints and ribbons using a degreasing solvent and a soft brush.
6. Record the resistance of each gauge again at the wiring terminals. Compare this to the resistances recorded in Step 1. This will confirm the integrity of the gage wiring ribbon at the wiring terminals.
7. Strip both ends of the strain gauge leadwires and inspect for nicks in the strands. Tin the wires at the wiring terminal end using the solder spheres.
8. Position the leadwires at the end of the gauge and provide a mechanical strain relief in the leadwires near the gauge.
9. Secure the leadwires to the surface of the test article and solder the wires to the gauge wiring terminals.
10. Remove the flux residue from the soldered areas using a degreasing solvent and a soft brush.
11. Wire routing should be preplanned with no wiring routed over the strain gauge active grids.
12. Check the resistance at the end of the leadwires to verify that the total resistance is appropriate for the gauge and it's lead wire system.
13. Check the gauge/wiring installation to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be greater than 10 Gig-ohms. Note: The type of wiring terminal recommended here is not rated to 650°F but the TL-56 terminal used originally for this task showed the ability to operate for hours at this temperature and it is felt that the LS-2 type terminal is a direct replacement and will perform in a like manner.

NOTE: The RTV-159 that is to be used as a moisture-barrier for the solder joints and gauge ribbons is also to be used for lead wire hold-down. Areas where the RTV-159 will be used for lead wire hold-down are to be lightly micro-sandblasted and cleaned prior to application of the RTV. The RTV should be kept at a minimum height over the wiring in order to prevent it from macro-cracking during cryogenic excursions.

Moisture-Proofing Procedure

1. Use pure alcohol to clean all areas that are to be covered with the RTV-159.
2. Apply a coat of RTV-159 (approximately 0.050" thick) over the gauge wiring terminals, solder joints, and gauge ribbons. Do not allow any of the moisture-barrier to be on the active area of the gauge. This application should be done with the test article and the RTV at a minimum temperature of 72°F and the relative humidity not more than 40 percent.

3. Allow the coating to air-dry overnight.

<u>APPLICATION CLASS V</u> – STRAIN SENSOR INSTALLATION PROCEDURES FOR BRAGG-GRATING TYPE FIBER-OPTIC STRAIN SENSORS

NOTE: Two basic and distinctively different types of fiber-optic strain sensors are now in use throughout the strain measurement community. One is the "Bragg-Grating" (B-G) sensor; the other is the "Extrinsic Fabry-Perot Interferometric" (EFPI) sensor. The EFPI fiber-optic strain sensor has been commercially available for some time and installation materials and procedures are straightforward and routinely provided by the manufacturer along with the sensors. The Brag-Grating strain sensors are now finding their way in the world of strain measurement but, to date, installation approaches for these sensors have not been forthcoming. Therefore, this section of the technical memorandum will detail materials and application procedures that have been employed at NASA Langley for installing the B-G type sensors for sensor-performance evaluation as well as actual applications on various structural test articles. These installation approaches are offered as a guide only, but should be useful in many testing scenarios for both metallic and composite test articles.

INSTALLATION TYPE 1 – Fiber-optic Sensors on Aluminum or Aluminum/Lithium

<u>Gauging Materials (all materials that are an integral part of the instrumented test article)</u>

1. Fiber-optic strain sensor, type: Bragg-Grating (typically furnished by testing engineer with specific, custom attributes driven by task requirements)
2. Fiber-optic strain sensor bonding adhesive, type: M-BOND 600 (Vishay Micro-Measurements)
3. Basecoat material for test article in areas to be instrumented with fibers, type: M-BOND 600 (Vishay Micro-Measurements)
4. Hold-down material for strain isolation area of fiber-optic sensor, type: RTV-159 (General Electric)

<u>Surface Preparation for Basecoating</u>

Note: The B-G type of fiber-optic sensor is typically selected where multiple strain measurements are desired in a given area, that area being comparatively large. With relatively large areas, the surface preparation process is more laborious and time-consuming than encountered when installing a conventional strain gauge. Because surface oxidation is a concern when bonding sensors on aluminum or aluminum/lithium, basecoating is recommended for the area to be instrumented.

1. Degrease the surface area to be basecoated with degreaser type: CSM-1A (Vishay Micro-Measurements) by saturating gauze sponges or lab-type tissues and wiping. Repeat until the sponges/tissues are clean.
2. Micro-sandblast the surface area using 50-grit or 80-grit Al_2O_3 abrasive powder.
3. Wipe the sandblasted area with gauze sponges or tissues saturated with M-Prep Conditioner A (Vishay Micro-Measurements).
4. Flood the surface with M-Prep Conditioner A and thoroughly scrub using gauze sponge.

5. Wipe clean and dry using dry gauze sponges/tissues. Wipe in one direction only and then discard the sponge for a new one.
6. Flood the surface with M-Prep Neutralizer 5A (Vishay Micro-Measurements) and thoroughly scrub using gauze sponges/tissues.
7. Wipe clean and dry using dry gauze sponges/tissues. Wipe in one direction only and then discard the sponge for a new one. Immediately upon completion of this step, the basecoat should be applied.

Application of Basecoat

Note: This basecoat is applied to prevent oxidation of the surface in the area to be instrumented. It is essential that the basecoat be applied immediately following the surface preparation. Therefore, the M-BOND 600 and the application tools, i.e., air brush, tapes, etc., should be made ready prior to the surface preparation steps.

1. Using an appropriate air brush (Paasche model SA 2000 works well) and M-BOND 600, coat the entire area where the fiber-optic strain sensors are to be bonded.
2. Air-dry this coating for a minimum of 10 minutes at room temperature.
3. Raise the temperature of the test article to 175°F. Hold at that temperature for four hours. The heating rate should not exceed 4°F/minute.
4. Cool the test article and inspect to verify the uniformity of the basecoat. Since this basecoating serves primarily to prevent surface oxidation, the thickness should be kept to a minimum. A coating thickness of 0.0005” will suffice.

Application of the Fiber-optic Strain Sensor

1. Clean the surface of the test article in the basecoat area where the fiber-optic strain sensors are to be located using 200 proof alcohol.
2. Mask the surrounding areas and lightly micro-sandblast or hand sand (400-grit Al_2O_3 paper works well) the basecoat sufficiently to remove any glazed appearance in the basecoat.
3. Remove the masking tape and clean the surface of the test article in the basecoat area where the fiber-optic strain sensors are to be located using 200 proof alcohol.
4. Place the fibers on the basecoated surface such that the strain sensing (indexed) areas of the fibers are in the pre-determined locations.
5. Tape the fibers in place. Typically, 1/8” wide strips of Kapton tape are used and the spacing of the tape strips will depend on the routing of the fiber with 2” spacing being typical.
6. Using a precision fluid dispensing gun (EFD brand works well) and an appropriate hypodermic dispensing tip, coat the fibers at the appropriate areas along their length using M-BOND 600.
7. Allow the cement to air dry for at least 30 minutes at room temperature.
8. Raise the temperature of the test article to 225°F. Hold at that temperature for 2 hours. Heating rate should not exceed 4°F/minute.
9. Cool the test article, remove the tape strips, clean the areas where tape strips were, and add additional M-BOND 600 to complete the installation.
10. Cure again as in Step 8.
11. The overall thickness of the M-BOND 600 should not exceed 0.003”.

12. Once all application and curing of the M-BOND 600 is satisfactorily completed, post cure the instrumented test article for 2 hours at 300°F. Heating rate should not exceed 4°F/minute.
13. Cool the test article and conduct electrical/optical checks to verify operability of the sensors.
14. Secure the unbonded areas of the B-G sensor as appropriate using spots of RTV-159.

INSTALLATION TYPE 2 – Fiber-optic Sensors on Composites from Cryogenic to 250°F

Note: The installation procedure described here includes the use of an adhesive system (M-BOND AE-15) that can be cured at temperatures below the maximum testing temperature of 250°F. Two other adhesives that have worked well for installing fiber-optic sensors on composites for testing scenarios ranging from cryogenic temperatures up to 400°F are the Vishay Micro-Measurements types: M-BOND 600 and M-BOND 610. The reason the M-BOND 600 is not recommended is that it's working time may be a detriment when installing a long run of the B-G type fiber. The M-BOND 610 works very well but does require a higher curing temperature than the M-BOND AE-15.

Gauging Materials (all materials that are an integral part of the instrumented test article)

1. Fiber-optic strain sensor, type: Bragg-Grating (typically furnished by testing engineer with specific custom attributes driven by task requirements)
2. Fiber-optic strain sensor bonding adhesive, type: M-BOND AE-15 (Vishay Micro-Measurements)
3. Basecoat material for test article in areas to be instrumented with fibers, type: M-BOND 600 (Vishay Micro-Measurements) Note: Basecoating may or may not be necessary depending on the texture of the composite.
4. Hold-down material for strain isolation area of fiber-optic sensor, type: RTV-159 (General Electric)

Surface Preparation for Basecoating

Note: Basecoating is not always needed when installing Bragg-Grating type fiber-optic sensors. The coarseness of the composite test article surface will dictate whether a basecoat is needed. The steps for applying a basecoat are provided here in the event it is required.

1. Degrease and clean the surface(s) to be instrumented. This is typically accomplished with a vapor degreasing solvent rinse, types: ENSOLV (Envirotech) or Hypersolve (Ecolink).
2. Perform a visual examination (microscopic when possible) of the areas to be instrumented and the test article in general, looking for flaws in surface, i.e., delamination, cracks, broken fibers, voids, sharp edges, etc.
3. Rinse the areas to be instrumented with ethyl alcohol 200 proof.
4. Mask appropriate areas of the test article for micro-sandblasting operation.
5. Micro-sandblast areas to be instrumented using 50 micron Al_2O_3 abrasive powder. When micro-sandblasting is not possible, use hand-sanding with 280 grit silicon-carbide abrasive paper.
6. Remove the masking materials, then, using dry shop air, remove abrasive powder residue.
7. Repeat the solvent degreasing and alcohol rinse operations.

Application of the Basecoat

Note: When a determination is made that a basecoat is required, a surface basecoat should be applied in all areas where the fiber-optic sensors will be bonded. Following are steps for surface basecoating prior to the actual sensor installation process.

1. Apply a liberal coat of M-BOND AE-15 adhesive to the sandblasted (or hand-sanded) areas with a thickness sufficient enough to cover the peaks of the textured surface.
2. Allow this coating to air dry for at least 10 minutes at room temperature, then, take the test article up to 200°F and hold it at that temperature for at least one hour. Then, cool to room temperature.
3. Once the basecoat is cured, it should be abraded until a uniformly textured surface is obtained. This hand-sanding operation should be performed using 280 grit silicon-carbide paper removing only an amount of the AE-15 sufficient to expose the fiber surface peaks.
4. Clean the basecoated areas once more with the alcohol.

Installation of the Fiber-optic Strain Sensor

1. Clean the surface of the test article in the basecoat area where the fiber-optic strain sensors are to be located using 200 proof alcohol.
2. Mask the surrounding areas and lightly micro-sandblast or hand sand (400-grit Al_2O_3 paper works well) the basecoat sufficiently to remove any glazed appearance in the basecoat.
3. Remove the masking materials and once again, clean the surface of the test article in the basecoat area where the fiber-optic strain sensors are to be located using 200 proof alcohol.
4. Place the fibers on the basecoated surface such that the strain sensing (indexed) areas of the fibers are in the pre-determined locations.
5. Tape the fibers in place. Typically, 1/8" wide strips of Kapton tape are used and the spacing of the tape strips will depend on the routing of the fiber with 2" spacing being typical.
6. Using a precision fluid dispensing gun (EFD brand works well) and a dispensing tip appropriate for the viscosity of M-BOND AE-15, coat the fibers at the appropriate areas along their length using M-BOND AE-15.
7. Allow the cement to air dry for at least 10 minutes at room temperature.
8. Raise the temperature of the test article to 200°F. Hold at that temperature for 1 hour. Heating rate should not exceed 4°F/minute.
9. Cool the test article, remove the tape strips, clean the areas where tape strips were, and add additional M-BOND AE-15 to complete the installation.
10. Cure again as in Step 8.
11. The overall thickness of the M-BOND AE-15 should not exceed 0.010".
12. Once all application and curing of the M-BOND AE-15 is satisfactorily completed, post cure the instrumented test article for 1 hour at 225°F. Heating rate should not exceed 4°F/minute.
13. Cool the test article and conduct electrical/optical checks to verify operability of the sensors.
14. Secure the unbonded areas of the B-G sensor as appropriate using spots of RTV-159.

INSTALLATION TYPE 3 – Fiber-optic Sensors on Composites from Room Temperature to 500°F

Notes: It should be noted that while the M-BOND 600 and 610 series adhesives have historically worked well at temperatures of 500°F and higher with conventional resistance strain gauges, they did not perform well in laboratory tests with the Bragg-Grating type fiber-optic sensors at temperatures exceeding 400°F. The Vishay Micro-Measurements type: M-BOND GA-61 did perform well with this type of sensor up to 500°F on a polyimide-type composite. This adhesive is quite viscous and its ability to function well cryogenically has not been tested.

<u>Gauging Materials – (All materials that are an integral part of the instrumented test article</u>

1. Fiber-optic strain sensor, type: Bragg-Grating (typically furnished by testing engineer with specific custom attributes driven by task requirements)
2. Fiber-optic strain sensor bonding adhesive, type: M-BOND GA-61 (Vishay Micro-Measurements)
3. Hold-down material for strain isolation area of fiber-optic sensor, type: RTV-159 (General Electric)

<u>Surface Preparation for Gauging</u>

1. Degrease and clean the surface(s) to be instrumented. This is typically accomplished with a vapor degreasing solvent rinse, types: ENSOLV (Envirotech) or Hypersolve (Ecolink).
2. Perform a visual examination (microscopic when possible) of the areas to be instrumented and the test article in general, looking for flaws in surface, i.e., delamination, cracks, broken fibers, voids, sharp edges, etc.
3. Rinse the areas to be instrumented with ethyl alcohol 200 proof.
4. Mask appropriate areas of the test article for micro-sandblasting operation.
5. Micro-sandblast areas to be instrumented using 50 micron Al_2O_3 abrasive powder. When micro-sandblasting is not possible, use hand-sanding with 280 or 320 grit silicon-carbide abrasive paper.
6. Remove the masking materials, then, using dry shop air, remove abrasive powder residue.
7. Repeat the solvent degreasing and alcohol rinse operations.

<u>Installation of the Fiber-optic Strain Sensor</u>

1. Clean the surface of the test article in the areas where the fiber-optic strain sensors are to be located using 200 proof alcohol.
2. Place the fibers on the surface such that the strain sensing (indexed) areas of the fibers are in the pre-determined locations.
3. Tape the fibers in place as per standard practice for Bragg-grating fibers using appropriate tape strips for elevated temperature applications (Kapton tape works well).
4. Using an EFD fluid dispensing hardware with a dispensing tip appropriate for the viscosity of M-BOND GA-61, coat the fibers at the exposed areas along their length using M-BOND GA-61.
5. Allow the cement to air dry for at least 10 minutes at room temperature.
6. Raise the temperature of the test article to 300°F. Hold at that temperature for 3 hours. Heating rate should not exceed 4°F/minute.

7. Cool the test article, remove the tape strips, clean the areas where the tape strips were, and add additional M-BOND GA-61 to complete the installation.
8. Cure again as in Step 8.
9. The overall thickness of the M-BOND GA-61 should not exceed 0.010”.
10. Once all application and curing of M-BOND GA-61 is satisfactorily completed, post cure the instrumented test article for 2 hours at a minimum temperature of 300°F. Heating rate should not exceed 4°F/minute

    Note: While the optimum cure would be at 375°F, it has been demonstrated that a post cure temperature of 300°F will suffice for B-G sensors even when 500°F test temperatures are encountered and curing of the actual test article at temperatures in excess of 300°F may not be practical.
11. Cool the test article and conduct electrical/optical checks to verify operability of the sensors.
12. Secure the unbonded areas of the B-G sensor as appropriate using spots of RTV-159.

April 18, 1994

TO: 238/Technical Files
FROM: 238/Senior Aerospace Engineering Technician
SUBJECT: Matching Cryogenic Strain Gages

INTRODUCTION:

There are inherent differences in the apparent strain curves of all transducer strain gages and since these differences are magnified at cryogenic temperatures, a resultant apparent strain is obtained when four of these strain gages are arbitrarily chosen and wired in a four-active arm Wheatstone bridge circuit. Therefore, it would be beneficial when designing cryogenic transducers with four active-arm strain gage bridges to have access to strain gages whose individual apparent strain curves are accurately predetermined and matched with respect to each other.

This matching of apparent strain curves is accomplished by means of a "temporary bonding technique" and through data comparison of a group of gages utilizing a computer program. The gages, following computer matching, will be disbanded and made ready for permanent installation.

This memorandum describes the "temporary bonding technique" and the steps utilized with the computer in the actual matching of the gages.

TEMPORARY BONDING TECHNIQUE FOR THE GAGES

(a) Gage Criteria – The gages to be temporarily bonded for matching should be one type and from one lot number. For cryogenic transducers, the gages typically will be Micro-Measurements type: C-891113-B. The optimum number of gages to be matched at one time with the current computer program is 16.
(b) Prior to installing the temporarily bonded gages, two strips of polyimide backing and 16 pairs of CPF-38C terminals are to bonded to the gage matching disc as shown on the attached sketch. These are to be cured in place using standard installation procedures for Micro-Measurements M-BOND 610.
(c) With the polyimide strips and the terminals in place, micro-sandblast the disc surface in the areas where the gages are to be temporarily bonded. Place the gages in position as shown in the sketch and bond them to the surface using M-BOND 200. Standard Micro-Measurements procedures for this adhesive are applicable.
(d) Next, using Micro-Measurements solder type: 361-A, solder the "gage-to-terminal" jumper wires between the gage solder dots and the CPF terminals. The jumpers should be a single conductor of AWG #40 silver-clad copper, each equal in length and resistance. The external leads should be stranded AWG #32 silver-clad copper with Teflon insulation and wired for 3-wire, quarter-bridge readout.

NOTE: The set-up and testing of the gages is described in the section that follows: "Disbonding the Temporary Gages".

DISBONDING THE TEMPORARY GAGES

(a) After the 16 gages have been "matched", an elevated temperature cycle will be incorporated to affect the bonding. The gaged disc should be placed in a temperature chamber. The temperature is then raised to 170°C and held for two hours. As the temperature approaches the 170°C level the gages disbond from the disc but remain suspended in place above the surface via the jumper wires that connect the gages to the lead wire terminals. During the two hours that the gages are soaking at the elevated temperature, the M-BOND 200 adhesive disintegrates leaving them virtually free of any material on the bottom side of the gage.
(b) Following the disbanding cycle the gages should be unsoldered from the jumper wires using a minimum amount of soldering iron tip heat. Next, each gage should be subjected to the following cleaning and surface preparation steps. 1. Flush each gage with Inhibisol; 2. Pumice the underside of each gage using S.S. White #3 grit powder' 3. Now, flush each gage with an ammonia base neutralizer followed with hot water; 4. Finish by flushing with 200 proof alcohol.
(c) After a microscopic examination of the underside of the gages to confirm there is no remaining residue, the gages should be cataloged for cryogenic transducer use as determined by the computer data that were generated during the gage matching run. (See the "Matching Apparent Strain Curves" section)

SET-UP AND TESTING OF THE GAGES

Following are the operating instructions for obtaining apparent strain data on 16 strain gages temporarily bonded to a metal disc as described above.

Equipment:
- Cryogenic Temperature Chamber
- 16 Bridge Completion Networks
- Temperature Readout for Type: T Thermocouple (Analog Output = 1mV/°C)
- 20 channel Balance Calibration Data Acquisition System (DAS)

SET-UP:

Place the strain gaged disc in an enclosure within the chamber. Route prewired gages and the thermocouple through the side port. Plug the port. Connect the gages to the bridge completion unit and the bridge completion unit to the data acquisition. Connect the thermocouple to temperature readout #1. Place the completion unit where it will not be subjected to changing temperatures or air currents. Connect a cable from the top red (+) and black (-) Banana Jacks on the bridge completion unit to the voltage input XLR connector on the front of the DAS (pin #1+, pin #2-, pin #3 shield). Connect a cable from the same set of Banana Jacks to the voltage sense connector on the front of the DAS. Connect a cable from the lower set of Banana Jacks to the voltage monitor connector. Connect cables 1 through 16 coming from the side of the bridge completion unit to channels 1 through 16 on the front of the DAS.

INPUTING INFORMATION AND SIGNAL CHECKOUT:

Load the program. The screen will present questions that pertain to the test to be performed. Read the questions carefully. Type in the answer while watching the screen to be sure no mistake is made. If a mistake is made press the "clear" key in the top row of keys and re-enter the answer. When the instructions say "press key '1'", it is not referring to the number key 1 but to the special function keys 1 through 10 in the upper left-hand corner of the keyboard. After answering the "on screen" questions and before starting the test, the output of each channel should be reviewed with the voltmeter. Check each reading for value and stability. The input voltage (channel 0) should be 5.000 volts. Channels 1 through 16 should be between –0.005 and 0.005. Channel 17 should indicate the temperature of the test block times 1000. For example, a voltmeter reading of 0.025100 is 25.1°C (0.025100 x 1000 = 25.1) Any unusual reading or instability should be investigated before start the gage matching test run.

DATA ACQUISITION:

After completion of the system checkout, data acquisition is commenced. Conduct the test as follows:

1) Press Key 2 which records an electrical zero at the current temperature and prints out the headings and the electrical zeros. Now it waits for the starting temperature that was input.
2) The chamber should be set to go to the end point temperature chosen for this test and turned on.
3) Data will now be taken automatically by the system at the desired temperature intervals.
4) The test manager should check the test periodically to make sure the temperature is changing as anticipated and that the data being generated is not erratic.
5) Once the end point temperature has been reached, the chamber should be reset to return to room temperature.
6) When the temperature readout indicates that the temperature is starting to increase, press Key 5. The system will take data at this end point and start taking data at the desired intervals during the return to room temperature.
7) When the test temperature increases from cryo to –10°C, turn off the power supply to keep the condensation that forms on the disc from shorting out the gages.
8) Press Key 6 to stop the test and store the data.

NOTE: Key 9 can be pressed to view a plot of the apparent strain curves.

MATCHING APPARENT STRAIN CURVES

Gages are matched in groups of four. The four gages that will comprise a group will be reviewed for magnitude of signal in three areas. They are; (1)maximum output throughout the temperature excursion, (2)loop data, which is defined as a difference in output at a given temperature comparing that output when the excursion is going cold versus going hot, (3)non-linearity. The maximum allowable outputs for each of the parameters would be +/-.015mV/5V. Potential matches can be reviewed on screen with final selections of matched groups being cataloged for use as active four-arm Wheatstone bridge circuits for cryogenic transducers including wind tunnel balances.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01- 05 - 2004

2. REPORT TYPE
Technical Memorandum

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Suggested Procedures for Installing Strain Gauges on Langley Research Center Wind Tunnel Balances, Custom Force Measuring Transducers, Metallic and Composite Structural Test Articles

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Moore, Thomas C., Sr.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
23-761-20-5H

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER
L-19020

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA/TM-2004-213017

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 01
Availability: NASA CASI (301) 621-0390 Distribution: Nonstandard

13. SUPPLEMENTARY NOTES
An electronic version can be found at http://techreports.larc.nasa.gov/ltrs/ or http://ntrs.nasa.gov

14. ABSTRACT
The character of force and strain measurement testing at LaRC is such that the types of strain gauge installations, the materials upon which the strain gauges are applied, and the test environments encountered, require many varied approaches. In 1997, a NASA Technical Memorandum (NASA TM 110327) was generated to provide the strain gauge application specialist with a listing of `recommended procedures` for strain gauging various transducers and test articles at LaRC. The technical memorandum offered here is an effort to keep the strain gauge user informed of new technological enhancements in strain-gauging methodology while preserving the strain-gauging guidelines set forth in the 1997 TM. This document provides detailed recommendations for strain gauging LaRC-designed balances and custom transducers, composite materials, cryogenic and high-temperature test articles, and selected non-typical or unique materials or test conditions. Additionally, one section offers details for installing Bragg-Grating type fiber-optic strain sensors for non-typical test scenarios.

15. SUBJECT TERMS
Force and strain measurement; Strain gauge; Fiber-optic strain sensors; Strain-gauging methodology; Sensor installation procedures

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	72	(301) 621-0390

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18